

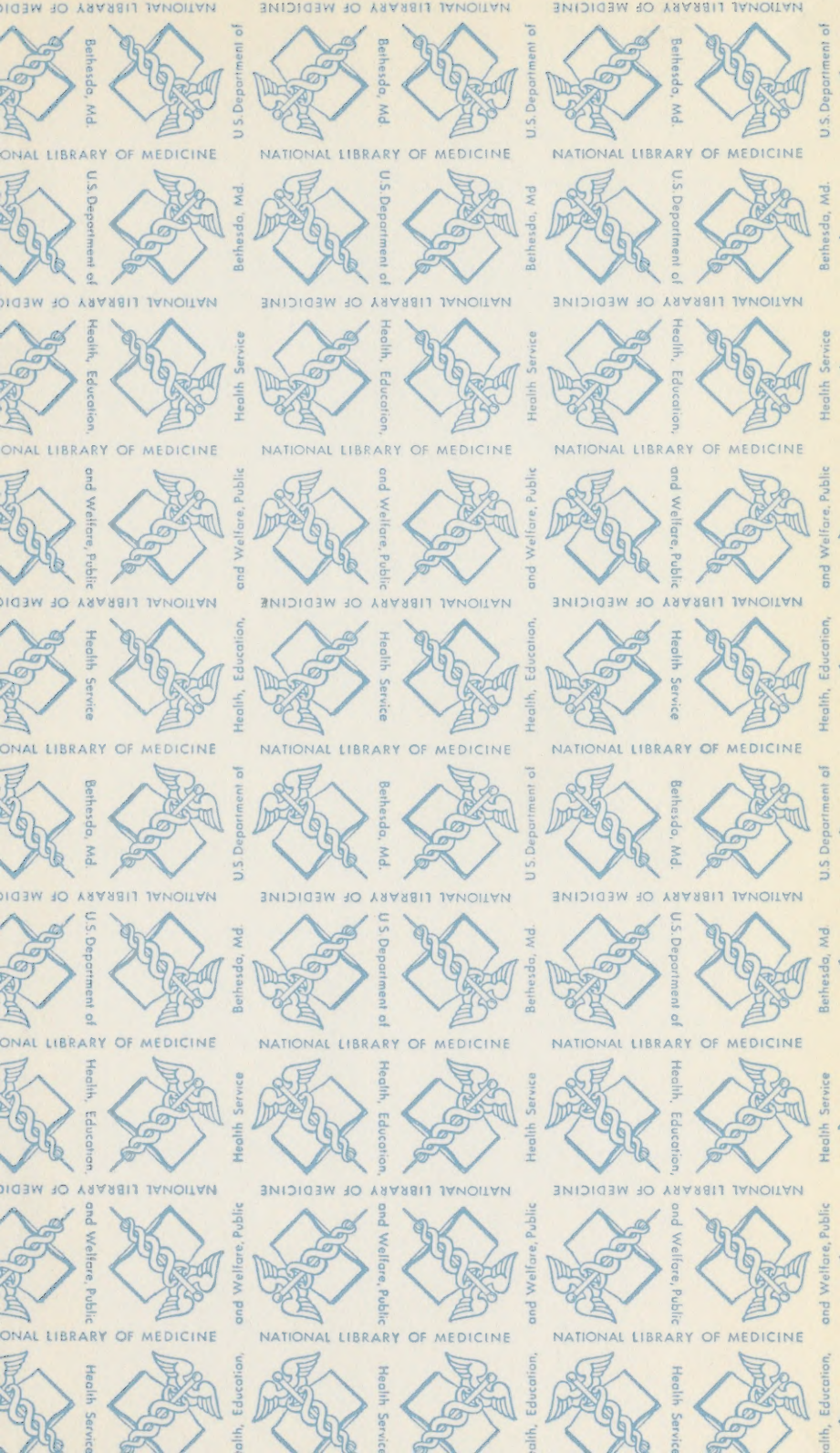
05031040R



NLM 05033619 9

NATIONAL LIBRARY OF MEDICINE





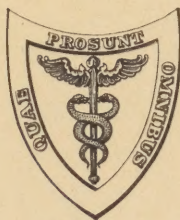
A TEXT-BOOK
OF
BIOLOGY

FOR STUDENTS IN GENERAL, MEDICAL AND
TECHNICAL COURSES

BY
WILLIAM MARTIN SMALLWOOD, PH. D. (HARVARD)
PROFESSOR OF COMPARATIVE ANATOMY IN THE LIBERAL ARTS COLLEGE OF
SYRACUSE UNIVERSITY

4th ed., rev.
FOURTH EDITION, THOROUGHLY REVISED

ILLUSTRATED WITH 229 ENGRAVINGS AND 3 PLATES IN COLORS



LEA & FEBIGER
PHILADELPHIA AND NEW YORK
1920



QH
308
5635t
1920

COPYRIGHT
LEA & FEBIGER ✓
1920

R
©Cl.A576073 L

AUG 16 1920 ✓
no 2

DEDICATED

TO MY ALMA MATER

SYRACUSE UNIVERSITY

IN RECOGNITION OF HER COMPLETION OF FIFTY YEARS OF SERVICE TO
EDUCATION.

PREFACE.

IN this edition the general plan of the previous editions has been retained and supplemented by considerably enlarging some chapters and adding new ones, and has been made more evident by grouping the work into five parts as follows: The fundamental principles of biology as illustrated by a complex animal—the frog; the fundamental principles of biology as illustrated by unicellular organisms; plant and animal types illustrating biological principles; some biological adaptations; theoretical interpretations.

Attention is called to "Laboratory Outlines," by Hargitt and Hargitt, which meet the needs of those wishing laboratory directions for the present edition. This book may be secured by writing directly to Professor C. W. Hargitt, Syracuse University, Syracuse, N. Y.

The historical development of biology, typified in large part by the emphasis which certain great men placed first upon one aspect of living things and then upon another, affords a natural approach to our subject: Linnaeus (1707–1778) emphasized the external form of organisms, while Haller (1708–1777) inquired into the general physiological activities of living things. These two men may be given credit for defining the two lines of study, morphology and physiology, which enter so largely into all modern courses in biology.

Cuvier (1789–1832) gave to the morphological study of organs a greater importance than his predecessors and Müller (1801–1858) a little later threw into prominence the function of organs. Next the organs were found to be made up of tissues and Bichat (1771–1801) gave particular attention to their composition and work. All of the investigations up to this time had failed in part because the ultimate structure of the organism was unknown.

With the discoveries of Schleiden and Schwann (1836–1840), that all living things can be analyzed into cells, a morphological basis for biological study was established. The name of Virchow (1821–1903) may properly be linked with the physiological study of cells. Dujardin (1801–1860) gave a great deal of attention to protoplasm and Bernard (1813–1878) emphasized the importance of protoplasm in analyzing physiological activities.

Biology has come through a series of natural steps to the present-day point of view, which aims to interpret biological problems in terms of protoplasm. The historical method has a pedagogical value which is lacking when a course in biology begins with cells, for in this plan of study the student continually passes from what he knows to what is new, from the general to the specific. But relatively few organisms are composed of single cells—nearly all living things are complex. We have to deal with organisms as they exist today, and this is the chief problem which the student in a beginner's course has to meet.

In the study of the frog we have an organism that is large enough to be easily seen and handled. It is analyzed in terms of its relation to other animals, in terms of its organ systems, in terms of its food and in terms of its method of reproduction. In each instance the analysis continues until the biological unit, the cell, is reached.

After the student has been introduced to the ultimate structure of living beings by this method of study it is easy to examine some unicellular organisms (Chapters VIII to XI). In the study of the life of the unicellular organism the student soon discovers that the essential life-characteristics of the frog are all present in these microscopic animals and plants. These are biological facts of large importance. A substantial although inadequate foundation has now been laid for the important question, *What is life?*

With these fundamental questions presented a certain amount of variation and latitude is to be expected in the sequence and content of the remainder of the course.

It is the conviction of the writer that the student should first be given an opportunity to study the actual animals and plants before the principles of structure, activity, etc., are taken up. Such a method furnishes him with a few concrete facts which he has secured himself. This tends to make the laboratory work the important part of the course, as it should be. The subject-matter of this book is therefore mostly written on the assumption that the student has already acquired some first-hand information in the laboratory.

It is difficult to determine one's exact indebtedness in the preparation of a text that attempts to deal with the broad principles of biology. So much has been written about these principles, and I have had the opportunity of inspecting the methods employed by so many of the leading teachers in many of the eastern and middle-western universities, that I find it impossible to differentiate between the ideas that are wholly the result of experience and those that have come through suggestions from my reading and associations.

I am under specific obligations to Professor Loren C. Petry for permission to reprint Chapter IX from the third edition; to a number of friends who have furnished me with photographs and to whom credit is given in connection with each figure; to Messrs. Lea & Febiger for numerous courtesies; to Elizabeth Clark, who has made under my direction practically all of the original drawings; and to my wife for reading the entire proof.

W. M. S.

SYRACUSE, N. Y., 1920.

CONTENTS.

PART I.

THE FUNDAMENTAL PRINCIPLES OF BIOLOGY AS ILLUSTRATED BY A COMPLEX ANIMAL—THE FROG

CHAPTER I.

ORGANISM.

Movement	17
Organism Defined	19
Amphibia	19

CHAPTER II.

ORGAN SYSTEMS—SCOPE OF BIOLOGY.

Digestive Canal	26
Digestive Glands	28
Respiratory Organs	28
Urogenital Organs	30
Cœlom	32
Organ Systems	32
Scope of Biology	33

CHAPTER III.

PHYSIOLOGY OF DIGESTION IN THE FROG.

Need of Food	35
Kinds of Food	36
Proteins	36
Carbohydrates	37
Fats	37
Digestion	38

CHAPTER IV.

CIRCULATION—METABOLISM.

Heart	42
Blood	43
Respiration	45
Metabolism	47
Metabolic Water	49

CHAPTER V.

TISSUES AND CELLS OF THE FROG.

Histology	51
Histology of Intestine or Stomach	51
Tissues	52
Epithelial	52
Connective	53
Muscular	54
Nervous	55
The Cell	55
Cell Theory	56
Protoplasm	57

CHAPTER VI.

NERVOUS SYSTEM OF THE FROG.

Nervous System	58
Tissues of the Central Nervous System	62
Origin of the Processes	65
Histology of the Spinal Cord	65
Nerves	66
Stimulation of Nerves	67
Habit Formation in Frogs	67
Organic Movement	68

CHAPTER VII.

EMBRYOLOGY.

Somatic and Germ Cells	69
Ova and Sperm Cells	71
Maturation	74
Fertilization	78
Segmentation	79
Tadpole	81
Life Cycle	83

PART II.

THE FUNDAMENTAL PRINCIPLES OF BIOLOGY AS ILLUSTRATED BY UNICELLULAR ORGANISMS.

CHAPTER VIII.

PARAMECIUM—AN ANIMAL MADE UP OF A SINGLE CELL.

Habitat	85
Appearance	86
Structure	86
Physiology	89
Locomotion	90
Movement in Ameba	91
Food	92
Digestion	92
Excretion	93
Respiration	93
Metabolism	93
Reproduction	93
Conjugation	93
Organic Movement	94
Kinds of Paramecia	95
Protozoa	96
Protozoön Animals	96
Biology of Cells	97

CHAPTER IX.

PLEUROCOCCUS—A PLANT CONSISTING OF A SINGLE CELL.

Habitat	98
Morphology	98
Photosynthesis	100
Other Materials and Syntheses	102
Metabolism	102
Reproduction	103
Other Unicellular Green Plants	103

CHAPTER X.

BIOLOGY OF BACTERIA AND YEAST—THE SIMPLEST LIVING ORGANISMS.

Organized Ferments	104
Yeast	104
Morphology	104
Reproduction	105
Food	105
Metabolism	106

Bacteria	106
Relationships	106
Morphology	107
Size	107
Structure	108
Motility	108
Reproduction	108
Zoöglea	109
Metabolism	109
Enzymes and Toxins	110
Fermentation	111

CHAPTER XI.

WHAT IS LIFE?

Spontaneous Generation or Abiogenesis	112
Chemical Composition of Living Matter	113
The Physical Properties of Protoplasm	116
Fibrillar Theory	116
The Alveolar Theory of Bütschli	116
The Biological Properties of Protoplasm	117
Relation of Life to the Living Body	117
Size of Living Bodies	119
Age of Living Bodies	119
The Cell and Living Protoplasm	119
Reproduction and Life	120
Growth and Life	120
The Awareness of Living Protoplasm	121
Maintenance of Life	121
The Fate of Dead Organisms	121

PART III.

PLANT AND ANIMAL TYPES ILLUSTRATING BIOLOGICAL PRINCIPLES.

CHAPTER XII.

SOME LOWER PLANT TYPES.

Thallophytes	123
Chlorophyceæ, the Green Algæ	124
Spirogyra	124
Vaucheria	125
Phycomycetes, the Algæ Fungi	127
The Bread Mould	128
Water Moulds	129

CHAPTER XIII.

SPERMATOPHYTA—TRILLIUM GRANDIFLORUM.

Spermatophyta.	131
Seed	131
Trilliums	132-141

CHAPTER XIV.

SOME INTERMEDIATE TYPES AND HYDRA—AN ANIMAL MADE UP OF
TISSUES ONLY.

Intermediate Types	142
Kinds	145
Morphology	145
Food	145
Structure	146
Nematocysts	147
Locomotion	148
Reproduction	149
Asexual Method	149
Sexual Method	149
Regeneration	152
Physiology	154
Winter Life of Hydra	157

CHAPTER XV.

THE "WORM" GROUP—THE EARTHWORM AS A TYPE.

External Morphology	158
Habits and Special Senses	159
Organ Systems	159
Reproduction	160
Regeneration	162
Histology	163
Intelligence of Earthworms	165

CHAPTER XVI.

MOLLUSCA.

General Characters	167
Food of Clams and Oysters	169

CHAPTER XVII.

THE CRAYFISH.

Kinds and Distribution	171
Food	171
General Characteristics	171
Modified Somites	172
Exoskeleton	172
Jointed Feet	173
Organ Systems	175

CHAPTER XVIII.

INSECTS.

Number	181
General Characters	181
The Honey Bee	181
Kinds	182
The Honey Bee Colony	182
The Queen	182
Drones	183
Workers	183
Structure of the Honey Bee	183
Respiration	184
Reproduction	185
Honey	186
Pollen Collecting	187

PART IV.

SOME BIOLOGICAL ADAPTATIONS.

CHAPTER XIX.

PARASITISM—GREGARIOUSNESS.

Adaptation	193
Parasitism	195
Classification of Parasites	195
Extent of Parasitism	198
Parasitic Habits	198
White-pine Blister Rust	201
Why Are Parasites Sometimes Very Numerous?	203
Symbiosis	204
Community Life	206
Gregariousness	206

CHAPTER XX.

ADAPTATION AND DISEASE.

The Role of Biology	209
Rattlesnakes	210
Amanita	212
Sporotrichosis	213
Crown Gall	215
Malaria	217
The Bacterial Diseases	218
The Filterable Viruses	220
Tapeworms, Hookworms and Others	220
Animal Tumors	221
Disease Carriers	222
The Prevention of Disease	225
Immunity	226
Protection and Adaptation	228

CHAPTER XXI.

OTHER ADAPTATIONS.

Oxygen	232
Food-getting	232
Sense Organs	232
Reproduction	233
Regeneration and Grafting	235
Habit Adaptations	236
Color	237
Plasticity of Protoplasm	237

PART V.

THEORETICAL INTERPRETATIONS.

CHAPTER XXII.

THE SCIENTIFIC METHOD	239-242
---------------------------------	---------

CHAPTER XXIII.

THE SIGNIFICANCE OF FOSSILS	243-251
---------------------------------------	---------

CHAPTER XXIV.

GEOGRAPHICAL DISTRIBUTION AND THE MEANING OF COLOR . 252-261
Meaning of Color 257

CHAPTER XXV.

VARIATION.

Variation 262
 Definition 262
 Variation in Paramecia 262
 Variation in Earthworms 263
 Variation in Crayfish 264
 Variation in Insects 266
 Variation in Ranunculus 267
 Methods of Studying Variation 267

CHAPTER XXVI.

HEREDITY.

Defined 269
Heredity and the Cell 270
Mendelism 274

CHAPTER XXVII.

EVOLUTION.

Facts to be Explained 287
Embryology 287
Evolution 288
Lamarek 290
Darwin 292
Appendix 301

PART I.

THE FUNDAMENTAL PRINCIPLES OF BIOLOGY AS ILLUSTRATED BY A COMPLEX ANIMAL—THE FROG.

CHAPTER I.

ORGANISM.

Movement.—The steam engine, the printing press or gliding aëroplane never fail to excite our admiration. The complicated machinery operates on almost frictionless bearings in accomplishing marvellous results, but none of these wonderful products of the inventive skill of many minds equals the frog when considered simply as a machine. Jumping and swimming involve a series of movements that are much more complicated than simply straightening out the limbs. Each limb takes a definite direction, one that is selected, and this alone places the movement of a limb as superior to the most perfect machine. In order that there may be selection in the direction of the movement of a limb, there must exist muscles capable of causing the limb to go in a given direction; but muscles need something to which they can be attached in order to make these selected movements. Such a framework is furnished by the bones. Bones and muscles alone are not capable of producing a given result. There must be a directing agent, something responsible for the movement and the selection. This is the work of the central nervous system and of the nerves that end in each muscle. The frog thus analyzed is easily seen to be more complicated than any machine. One of the reasons why the term living is given to the frog is because it can make these selective movements of the limbs. For the name frog may be substituted the name of any other object that has biologically, not humanly, speaking this same property of exercising choice in its movements and the term living can be applied to it.

There is movement in a variety of things in Nature. A familiar example is that of the wind. While the usual paths of the wind are known and charted, and it has been determined that the cause of the wind lies largely in differences in temperature and barometric pressure, yet there is nothing here that is comparable to the selected direction of movement in a living animal. Gunpowder and the various explosives have each a characteristic movement, but they all remain in a static condition unless acted upon by some outside stimulus, as the lighted fuse, and then their movement is of one kind. Movement considered from a physical or chemical standpoint is of the same nature whether in inanimate or animate Nature. But there is always in animate movements the additional regulative factor which permits movement to be regarded as one of the fundamental properties of living matter though there are seasons or periods in the life of many animals when movements cease and the animal becomes quiescent.



FIG. 1.—*Rana catesbiana*, the bull-frog. (Photograph furnished by American Museum of Natural History.)

The four legs of the frog move in such a manner as to produce a given result, the two eyes reveal the same picture, the complicated changes in breathing result in drawing air into the lungs and allowing it to escape, and many other equally difficult changes are taking place continually. Anything which can produce these peculiar changes is alive and is called an organism.

Organism Defined.—The term organism is given to any particle of living substance capable of independently sustaining itself. "*An organic individual is a unitary mass of living substance which under definite vital conditions is capable of self-preservation.*" This definition is so formulated as to include every condition under which living things have come to live, the minute bacteria or the large elephant, the simple worm or the group of individuals in the ant community.

These definitions include all forms of living things, but because many of them are so simple the following, "An organism is composed of organs" does not apply, although it describes and defines correctly the frog as it does all large animals and is the most used and familiar definition. Whenever this latter definition can be used the animal is complex, consisting of many highly specialized parts, as arms, legs, eyes, ears, taste and touch organs, etc. Each of these has a given work to do and is called an organ. Only a few of the organs in the frog have been observed as yet in this course, but others will be worked out later. *An organ is a structure which does a given work for the organism and is itself composed of many distinct parts.*

Amphibia.—A long time ago when men first became interested in animals they arranged them into certain groups, because all of the members of the group possessed certain structures in common. The presence of an internal skeleton alone (Fig. 2) suffices to relate an animal to all of the rest of the animals possessing a similar skeleton, and it is called a *vertebrate*. Cuvier first advanced the view, in 1795, that all animals were constructed upon four distinct plans. Of these four plans, the vertebrate alone has stood the test of modern scholarship. Ever since Cuvier propounded the term *vertebrata* it has embraced five classes: The pisces, amphibia, reptilia, aves and mammalia (see Appendix). The pisces are exclusively aquatic animals and the reptilia are mostly terrestrial in their habits. In between these two classes is placed the amphibians, which are both aquatic and terrestrial in habit. Their habit of thus living in water and on land explains the meaning of the term *amphi*, both; *bios*, life. The amphibians afford one an opportunity to study the manner in which aquatic vertebrates may have become terrestrial. Not only will you find some of the amphibian structures in an intermediate stage between those of fishes and reptiles, but in an exceedingly simple state of development. No other group of vertebrates illustrates as many biological principles as this group of animals.

As early as 1758 Linnaeus had devised a method of naming animals and plants that was to become a permanent part of the science of

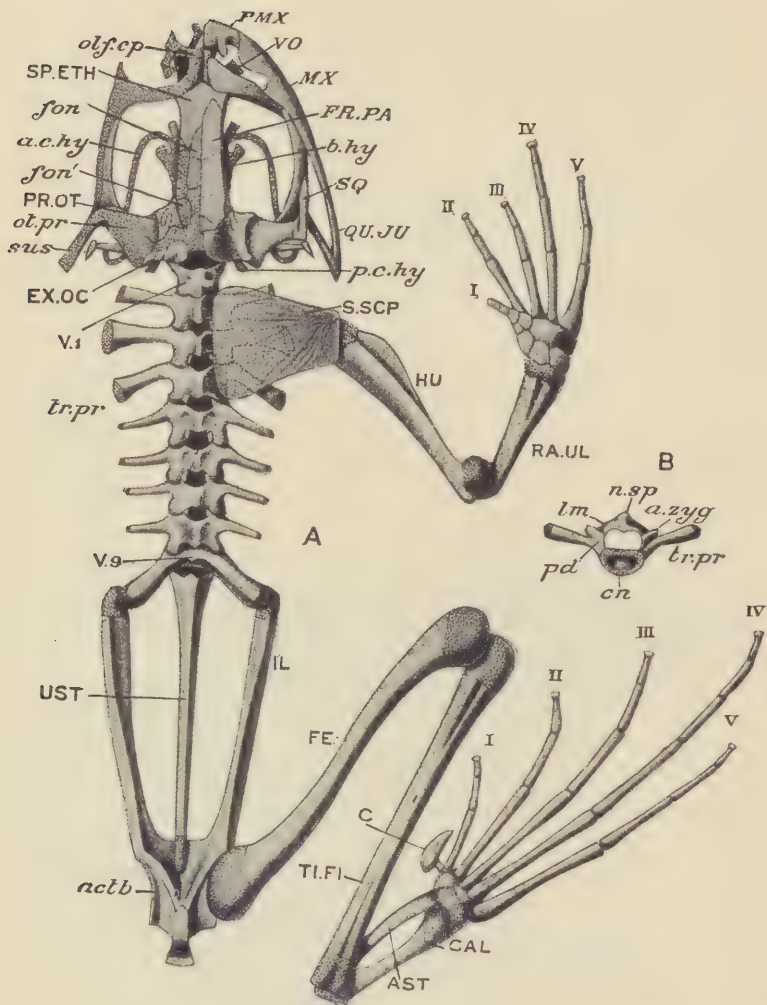


FIG. 2.—*Rana temporaria*. A, the skeleton from the dorsal aspect; the left half of the shoulder girdle and the left fore and hind limbs are removed, as also are the membrane bones on the left side of the skull. Cartilage parts dotted *a.c.hy*, anterior cornu of hyoid; *actb*, acetabulum; *AST*, astragalus; *b.hy*, basihyal; *C*, calcar; *CAL*, calcaneum; *EX.OC*, exoccipital; *FE*, femur; *fon*, *fon'*, fontanelles; *FR.PA*, frontoparietal; *HU*, humerus; *IL*, ilium; *MX*, maxilla; *olf. cp*, olfactory capsule; *ot.pr*, otic process; *p.c.hy*, posterior cornu of hyoid; *PMX*, premaxilla; *PR.OT*, prootic; *RA.UL*, radioulna; *SP.ETH*, sphenothmoid; *SQ*, squamosal; *S.SCP*, suprascapula; *sus*, suspensorium; *TI.FI*, tibiofibula; *tr.pr*, transverse process; *UST*, urostyle; *V.1*, cervical vertebra; *V.9*, sacral vertebra; *VO*, vomer; *I-V*, digits; B, the fourth vertebra, anterior face; *a.zyg*, anterior zygapophysis; *cn*, centrum; *lm*, lamina; *n.sp*, neural spine; *pd*, pedicle; *tr.pr*, transverse process. (After Howes, slightly altered, from Parker and Haswell.)

biology. His plan was to use two words which should show their general relations and individual differences. For example, the cat-like animals were given the generic name of *Felis*, and all that is necessary in naming these animals is to add to *Felis* a specific name, as *domesticus*, for the common cat, or *Felis canadensis* for the Canada lynx. In a similar way the dog-like animals were united under the genus *Canis*, and so there is *Canis lupus*, the wolf; *Canis vulpes*, the fox; or *Canis familiaris*, the common dog. A species is usually defined as a number of animals that resemble one another *so closely that to know one is to know all*.



FIG. 3.—*Rana sylvatica*. (Photographed by M. C. Dickerson.)

If we now apply the method of classification devised by Linnaeus to the frogs studied in the laboratory, we find that the term *Ranidæ* is given to all true frogs, of which there are one hundred and forty different species known in the whole world, with sixteen occurring in North America. The term *Rana* thus becomes the generic name for frogs, and all that is necessary is to add a name for specific features such as *Rana pipiens*, *R. catesbiana*, the bull frog; *R. clamitans*, the green frog; *R. palustris*, the yellow-legged frog; *R. sylvatica*, the wood frog (Fig. 3), etc.

The old definition of species given above was formulated before the present-day intensive study of variation and experimentation (see Chapters XXV and XXVI), which has yielded facts that make it very difficult to define a species exactly. This is due in part to the fundamental facts which you have already discovered, *i.e.*, that no two individuals of *Rana pipiens* which you studied in the laboratory were exactly alike, and as you compared your specimens with others a still larger number of differences were noted. Now, if you should make an intensive study of the several species of frogs in New York State, for example, you would find some of the species varying in such a manner that the same individual would be classified as belonging to two



FIG. 4.—*Rana draytonii*, a frog from the Pacific slope. (Photograph furnished by American Museum of Natural History.)

species. This has actually happened in the case of the common frog in northern Michigan and the Adirondacks, which was recently classified by an expert on amphibians as *Rana catesbiana*, but which a more intensive study on his part convinced him should be classified as *Rana clamitans*.

In order that there may be some definiteness in our descriptions of animals and plants, arbitrary limitations have been placed upon species. It is wise to accept this practice until some better method is devised and receives general acceptance, so we may use this old definition as a working basis for the purposes of this course.

Habits.—The general habits of the group will be illustrated by describing *R. catesbiana*. The amphibia are all aquatic for a part

of the time and but few of them (toads) remain away from the water for any length of time.

Rana catesbiana is the largest of the North American frogs and is commonly found with a body six to eight inches long when adult.



FIG. 5.—Linnaeus at sixty years, 1707–1778. (From Locey's *Biology and its Makers*.)

Carl von Linné or Linnaeus introduced the method of naming plants and animals that is used at present and is the founder of the modern methods of classification. He confined his studies chiefly to such descriptions of living things as are illustrated in the text by *Rana catesbiana*. He represents the beginning of the scientific study of biology, which was concerned with the general external appearances of organisms, and which is known now as the science of taxonomy.

The following technical description illustrates how a taxonomist described a given species of frog. You should make a similar study in the laboratory: In color the body is green or greenish-brown. The back and sides may be plain in color or may be darkly spotted. Spots distinct or connected. Arms and legs spotted or barred with

dark. Under parts white, distinctly or obscurely spotted and mottled with dark color. Throat of male may be yellow. Iris of eye is either golden or reddish bronze. The femur is about equal in length to the tibia. Head broad and flat; body stout and flat; ear of male larger than eye; ear of female about the size of the eye. Toes broadly webbed; no joints free except the last of the fourth toe. Hind leg 7 to 10 inches long. Such a description illustrates the first stage in the development of biology, the morphological period of Linnaeus.

This species of frog grows to a large size and may be found commonly with a body 6 inches long, although often secured much larger. They are quite abundant in northern ponds and streams. In fact, where they are abundant the other frogs are absent, probably because, being smaller, they are eaten by them. The bull frogs are usually found sitting partly buried in the soft mud or concealed by sticks or grass; when disturbed they dive to the bottom and stir up the mud; then swim back to the edge of the water, usually a foot or two from where they jumped. This habit and the color of their skin is their chief protection from snakes, mud turtles, fish, birds, etc.; they are defenceless unless thus concealed. Wright says that *R. catesbiana* is found along both upland and lowland streams, in clear brooks which feed cold, nearly sphagnum ponds, and also along water-courses laden with such marshy vegetation as lizard-rail, marsh-cress, arrowhead, pickerel-weed and swamp-loosestrife.

It is easy to catch them by dangling a hook variously baited in front of their noses. When this is moved slightly it is usually jumped at, although it may be held still against the nose for some time and be declined. Their food is selected from insects, worms, decaying meat, tadpoles and small frogs. The front leg is used in pushing large objects into the mouth. All food is swallowed immediately. The tongue is the chief organ used in securing small animals. It is thrown out and the passing insect is captured by the sticky secretion on its surface.

The evening croaking of frogs, especially *Rana catesbiana*, suggests that there is a sound-producing organ, and such is the case, for the sound results from forcing air past vocal cords. This voice of the bull frog is a sonorous bass with a good carrying power. "Blood 'n 'ounds," "be drowned," "jug-o-rum" are some of the expressions which are used to imitate the sound. The croaking begins about three weeks after the frog emerges from hibernation. Vocal sacs in the side of the neck of the male act as resonators but

are not capable of producing any sounds themselves. By holding a frog under water and gently rubbing it croaking can be produced. The air comes out into the mouth and is then returned to the lungs as if it were just being breathed into the mouth; the air is thus used over and over in sound production.

The activities of the frog are largely regulated by the seasons. Its body temperature is about that of the surrounding medium in which it lives; it therefore varies from season to season. The term cold-blooded is applied to fish, amphibia and reptiles because of their low and varying bodily temperature. During the winter the frog hibernates in the mud below the frost line. The vital activities are greatly lessened, the lungs emptied (cutaneous respiration sufficing), mouth closed, the heart beats feebly and slowly. The energy required to sustain this lowered vitality is taken in part from the muscles and accumulated fat. *R. catesbiana* is the last of the frogs to come out of hibernation. As soon as the water averages about 64° F. and the air 68° to 75° F., one may expect to find them appearing after their winter sleep. The tadpoles of *R. catesbiana* spend two winters in the larval stage. The legs do not begin to show until the second summer, during July and August. The frogs continue to grow for several years and may increase in size until ten years old. Compare the general habits, environment and tadpoles of the species of frog which you study in the laboratory with *R. catesbiana*. The general activities of the frog in which the whole body is more or less involved may serve as representing the physiological outlook in the time of Haller.

References in Movement and the Nature of an Organism.

CRAMPTON: The Doctrine of Evolution, Chapter I.

JORDAN AND KELLOG: Evolution and Animal Life, Chapter III.

RAND: The Problem of Organization, Science, 1912, xxxvi, 803, No. 937.

SCHAFER, E. A.: The Nature, Origin and Maintenance of Life, Science, 1912, xxxvi, 289, No. 923.

SPENCER: Principles of Biology.

VERWORN: General Physiology.

References to Amphibia.

COPE: Batrachia of North America, 1889, Bull. U. S. Nat. Mus., No. 34.

DICKSON: The Nature Library, Frog.

ECKER: The Anatomy of the Frog.

GADOW: Amphibia and Reptilia.

HOLMES: The Biology of the Frog.

WRIGHT: Life Histories of the Anura of Ithaca, N. Y., Carnegie Pub., No. 197.

CHAPTER II.

ORGAN SYSTEMS—SCOPE OF BIOLOGY.

Digestive Canal.—The digestive organs of the frog consist of a hollow tube or canal and connected with it relatively solid glands. The digestive tube begins with the mouth and ends with the anal opening. The mouth is edged with lip-like folds of skin and many

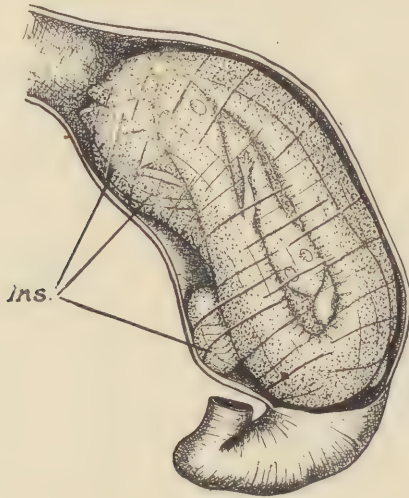


FIG. 6.—Stomach and contents of *Rana clamitans*. *Ins.*, insects. The salamanders belong to the genus *Plethodon*.

short conical teeth on the upper jaw. The opening itself is relatively large compared with the size of the whole animal; this enables it to eat large tadpoles and small frogs. The teeth are not used in tearing or grinding the food but rather assist in holding it when once seized. The tongue is attached at the tip of the lower jaw and is thrown out by the action of muscles forcing lymph into the tongue. On the roof of the mouth are found the vomerine teeth and beside them the internal nares. Near the angle of each jaw is the Eustachian opening which passes into what corresponds to the middle ear.

After the tympanic membrane is removed the solid, single ear bone, the columella, is seen and the short passage into the mouth. The mouth cavity narrows in the posterior region but continues as a tube into a short distensible esophagus. Just in front of this opening is the glottis leading into the lungs. The inner surface of the esophagus is folded and these folds continue into the stomach. There is no sharp boundary between esophagus and stomach. The anterior

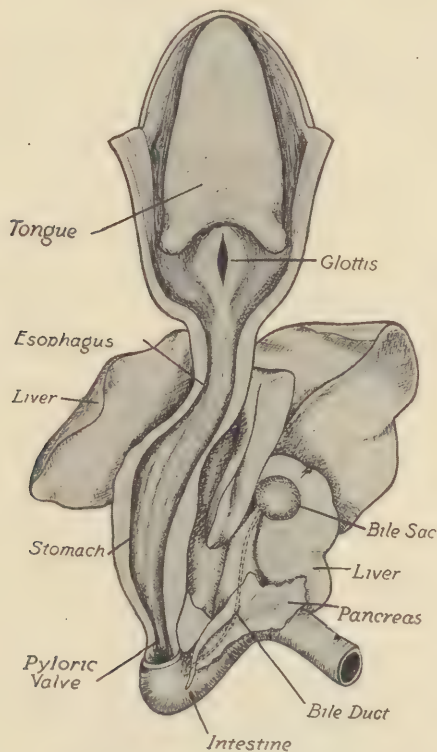


FIG. 7.—Digestive organs drawn from the dorsal surface.

end of the stomach is wider than the esophagus and known as the cardiac region, and from this region it tapers into the posterior or pyloric end, where a slight constriction, the pyloric valve, separates it from the intestine. Each region of the digestive tube has a characteristic shape; this is particularly true of the stomach, and an expert could readily isolate the correct drawing of a frog's stomach from that of any other vertebrate, such as fish, snake or man. The

position, however, which it occupies in the body, its terminology, its cardiac and pyloric regions and pyloric valve are the same as in all of the vertebrates. Passing from the spindle-shaped stomach the intestine is small, coiled and uniform in diameter until the large intestine is reached, where it becomes much larger. A special name, *cloaca*, sewer, is given to the posterior region of the intestine because of its relation to the urogenital organs, which simply means that this region is used by both the digestive and urogenital organs as a common passage to the exterior.

Digestive Glands.—There are probably no digestive glands in the mouth other than those that secrete the viscid fluid used on the tongue. The large liver, covering most of the digestive organs, and the small pancreas are true digestive glands that discharge their secretions through a single duct into the anterior end of the intestines. The liver which is red consists of three lobes, the small median lobe being covered by the heart. The whole liver is covered by a delicate membrane that holds it in place. A gall-bladder lies between the right and left lobes (Fig. 7), and appears greenish when full of bile, the liver secretion. The gall-bladder is connected with the lobes of the liver by several minute ducts. These are the hepatic ducts, some of which empty directly into the bile duct. The pinkish-white pancreas is located between the stomach and the first loop of the intestine. It is irregular in shape and through it the bile duct passes. Several pancreatic ducts discharge into the bile duct. Each gland as well as the intestine is held in place by a whitish, translucent membrane called the mesentery, that is attached to the back. On the mesentery of the small intestine is the small ductless gland, the spleen.

Respiratory Organs.—The skin and lungs are the important respiratory organs. The lungs are elongated, thin-walled sacs that are capable of great distention and their inner area is about equal to two-thirds of the total area of the skin. When the lungs are empty of air they become inconspicuous, wrinkled masses. Experiments have shown that the frog can live when deprived of the use of either the skin or the lungs in carrying on the work of respiration. That this work of respiration can be carried on by two very different organs illustrates well how the frog introduces oxygen into the blood. The oxygen of the air may thus pass through the skin or lungs into the blood. This portion of the process is external respiration. The frog breathes by drawing the air into the mouth, which produces an oscillation of the throat; then the external nares are closed and

the air in the mouth cavity is forced into the lungs. The movements of the throat do not correspond to the filling and emptying of the

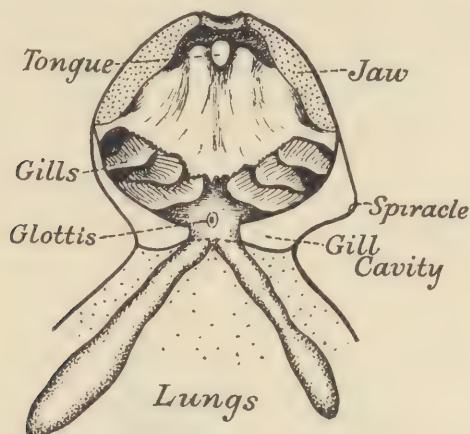


FIG. 8.—Floor of the mouth of tadpole, *Rana clamitans*, to show relation of gills and lungs. The tongue is just beginning to grow backward in the floor of the mouth.

lungs. During hibernation in the mud the skin is the chief organ of respiration. In the cold weather of fall frogs remain alive for

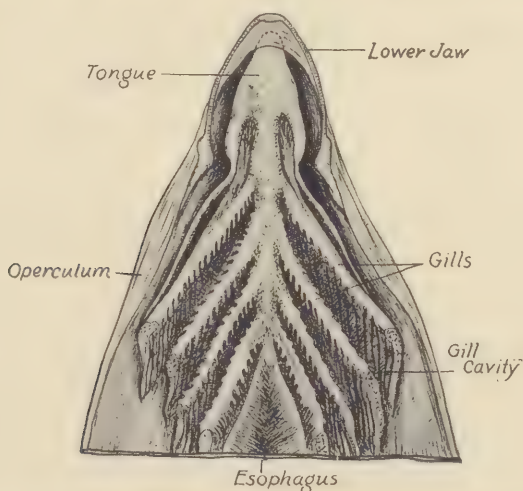


FIG. 9.—Floor of mouth of a fish. Compare Fig. 7. What conclusions can you draw?

some days completely submerged in water. It should be clearly understood that the lungs, skin and blood in taking oxygen from

the air or water and in carrying it to all parts of the body, are acting in a mechanical fashion and are not carrying on true respiration, because respiration proper is one of the fundamental vital processes and can take place only in the living cells (see page 45).

Urogenital Organs.—It is customary to discuss these two sets of organs under one caption because of their intimate structural connections in the male. The small red kidneys are elongated, flat bodies (Figs. 11 and 12), similar in the male and female frog. A short ureter in the female carries the urine from the kidney to the cloaca. From the cloaca the urea passes by gravity into the ventral bilobed bladder (Fig. 10).

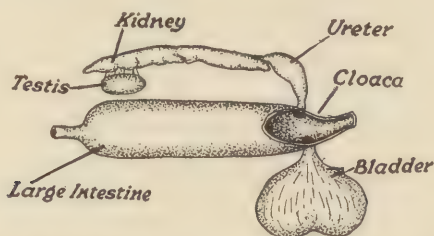


FIG 10.—Diagram to show the relation of the urogenital organs in the male frog.

On the median ventral surface of each kidney is the yellowish-white adrenal body. Each kidney is an organ that may be compared to a combined manufacturing and filtering plant. The removal of wastes from the blood is brought about in a twofold manner in the numerous microscopic tubules of which the kidney is composed. A single tubule consists of a filtering apparatus (the Malpighian body) and a glandular portion. In the Malpighian bodies wastes are strained out of the blood, while in the glandular portion of the tubules wastes are excreted.

The ovaries are usually very large, irregular organs surrounded by a thin membrane and attached to the back. There is no opening or duct leading from them. When the time arrives for the discharge of the eggs they are set free in the body cavity through many openings in the wall of the ovary. The long coiled oviducts are separate from the ovaries and from each other; each has a wide opening just dorsal to the stomach, into which (so far as we know) the eggs are forced by the general bodily movements. The posterior end of the oviduct is enlarged to act as a receptacle, *uterus*, for the eggs just prior to egg-laying; while most of the anterior portion is gland-

ular, secreting the egg jelly (Fig. 12). The oviduct empties into the cloaca. In the male the parts are more closely united. The small spermary is supported by a mesentery that holds it near the anterior end of the kidney. Through this mesentery pass a number of minute tubes that carry the sperms into the kidney (Fig. 11). After the sperms reach the kidney they pass through and escape into the cloaca by using the regular duct of the kidney, the ureter. The ureter of the male becomes enlarged near the posterior end for the

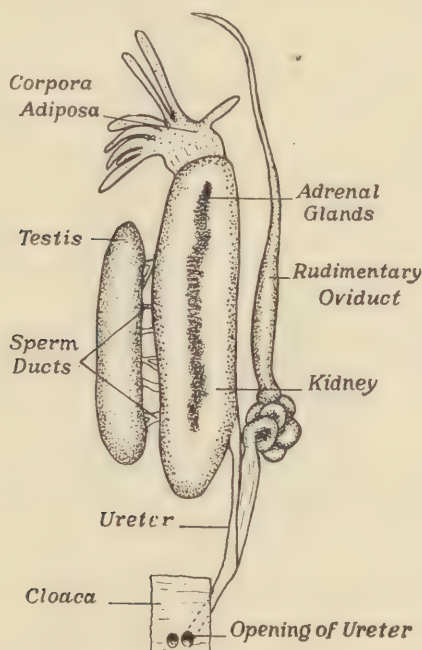


FIG. 11.—Male urogenital organs of the toad.

reception of sperms. Because this duct carries both urine and sperms it is called the urogenital duct. Critical dissection usually reveals the presence of a small coiled structure just outside of the urogenital duct which can be traced anterior to each kidney, where it becomes minute (Fig. 11). This is a rudimentary structure, *i. e.*, one that was of use to some ancestor of the frog but not now used. If the large oviducts of the female frog were greatly reduced in size they would look just like these structures in the male frog, which are designated rudimentary oviducts. There are many cases on

record of finding in the frog small ovaries variously associated with the spermaries. The rudimentary oviducts and the occasional presence of partly developed ovaries suggest that the ancestors of the frogs were hermaphroditic, *i. e.*, possessed both spermaries and ovaries. Attached to the anterior end of each kidney are the corpora adiposa (Figs. 11 and 12), which do not decrease in size until the period when the frog begins to grow eggs or sperms.

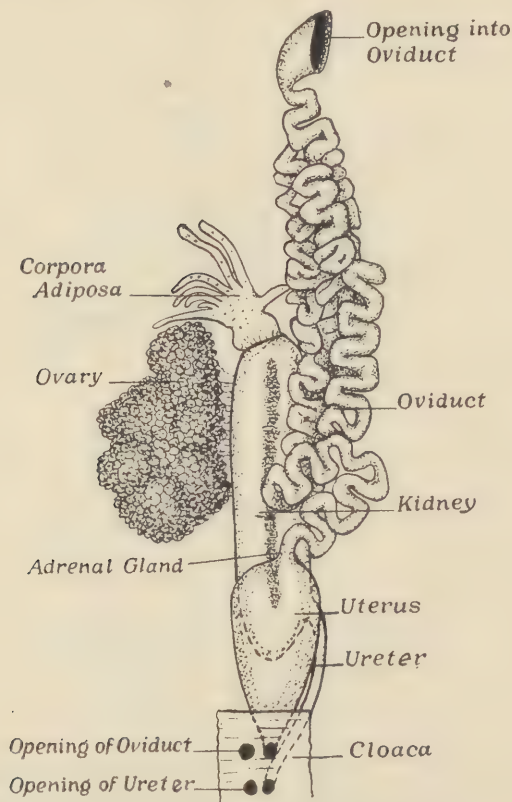


FIG. 12.—Female urogenital organs of toad.

Cœlom.—All of these organs are located in a large cavity which is termed the cœlom. It is on the ventral side of the body and is a common cavity in all vertebrates.

Organ Systems.—In any description of a set of organs to which a single name can be given certain intimate relations are implied.

While there are many different parts which may have widely different shapes, they all work in harmony to produce some single purpose, as the digestive organs in digesting food, etc. Here each organ does a given part of the whole work. The work is thus done better than if there were no such division into organs. This using of many organs in carrying out a single general work of an organism is characteristic of all complex plants and animals, and results in a system of organs. Each system of organs assumes a given work for the benefit of the organism, so that it is often described under the heading of physiological division of labor. This same principle describes accurately the difference between a complex civilization where most people are experts, that is, each does some one thing well, from that of barbarians where each does many things and these but indifferently. In the former case each is dependent upon many others for existence, while in the latter a single family often sustains existence and provides for all of its own wants. The frog would soon die if any of the organs were permanently removed from any of its organ systems. It would be likewise difficult for us to exist if those which supplied us with certain articles ceased to exist. This analysis of the body of the frog into definite organs marks the method of study made famous by Cuvier, who gave to the morphological study of organs such an importance that it may well stand for the second stage in the development of biology.

Scope of Biology.—Biology aims to ask four general questions about an organism: (1) What is it? (2) What does it do? (3) How does it arise? (4) How did it come to have its present form and relations? Each of these questions leads into rather well-defined lines of study. The discussion thus far has centered mainly around the first question. This study of the shape, structure and relation of parts is known by the technical term *morphology*; while the answer to the second question seeks to state the relation of these parts to the vital processes and is called likewise by a special term, *physiology*. A suitable answer to the third question involves the study of how each single organism comes into existence and grows into a mature organism, and this branch of biology is called *embryology*. The fourth question is more general and comprehensive, for it includes the history of any plant or animal family, and must needs consider the record left in the rocks as well as all of historic time and the relation of its environment as an influence on the development of the family. This phase of biology is called *evolution*. Every organism may be studied from these four points of view; but these are very general terms and the

science of biology has made marvellous progress, so that each of these great subdivisions is again divided into special departments of biological learning, a mere statement of which will suffice.

Biology	1. Morphology	- Anthropology - Anatomy - Histology - Taxonomy	Applied to medicine, forestry, agriculture, domestic science, physical education.
	2. Physiology	- Physiology, general and human - Psychology - Sociology	
	3. Embryology		
	4. Evolution	- Heredity - Variation - Distribution - Racial history	

CHAPTER III.

PHYSIOLOGY OF DIGESTION IN THE FROG.

Need of Food.—While the frog cannot tell us in words that he requires food, yet we are as certain that he does as if he could say "I am hungry." In fact, that is just what his actions mean when we make him jump along the bank after a baited hook. Because the frog is an animal and because man is an animal in just the same sense, we are justified in using many facts that we know about man in our attempt to explain the work of the various organs of the frog. In this sense the chapter heading might read the "physiology of digestion of animals."

The need for food is fundamental with all living things, because they all use energy in living, and energy is something that is not created but exists all of the time in one form or another. The frog as a typical animal shows the relation of this energy as it exists in the form of food. The frog expends energy in three conspicuous ways: (1) In every movement of the body there is an expenditure of energy in the contraction of the muscles. The frog can be made to jump continuously for a time, but soon the jump grows short and it needs a stronger stimulus to cause it; after a little longer time the frog refuses to jump, the muscles are, so far as general observation goes, just the same as when the first jump was made; but after this severe muscular exertion there is a condition of exhaustion until the muscles can be supplied with more food. It is well known that the simple elements which unite to make proteins or carbohydrates do not act as a food when fed to the frog until combined into such complex substances as enable them to be chemically classified as foods. The frog is like all other animals in requiring that its food be ready-made: it has no power to manufacture food out of the raw chemical elements. (2) The need for energy arises because of the periodic production of a large number of eggs by the female and many sperms by the male; both eggs and sperms are living and as such have been grown. The production of the living germinal substance, especially the egg, utilizes a large amount of energy that is indirectly supplied by the food eaten. (3) The body of the frog, while in a large measure subject to the surrounding temperature, does utilize

energy to some extent in the production of heat. This keeping the body warm is a more conspicuous expenditure of energy in birds and mammals, where a constant bodily temperature is maintained. Unless the frog can meet these three needs of the body it soon dies; that these three needs are supplied there is abundant evidence.

Kinds of Foods.—Laboratory study shows that they are commonly divided into proteins, carbohydrates and fats; to these three must be added water and certain salts which are either taken separately or as a part of the foods.

Proteins.—One of the chief constituents of living cells is protein. This is a complex substance always containing carbon, hydrogen, nitrogen, oxygen; while sulphur, phosphorus, iron, copper, iodine, manganese and zinc are of frequent occurrence in the protein molecule. These several chemical elements exist in about the following percentages:¹ Carbon, 40 to 55 per cent.; hydrogen, 6 to 7.3 per cent.; oxygen, 19 to 24 per cent.; nitrogen, 15 to 19 per cent.

The frog secures his proteins from the flesh that he eats, as all lean meat belongs to this class of foods. As the frog is not very particular in the selection of his food, he may get some plant proteins. Recently the biological chemists agreed upon the following classification for plant and animal proteins: Simple proteins, conjugate proteins and derived proteins.

The simple proteins are such substances as albumen in egg and some vegetables, or the globulins, fibrinogen or plant vitellin. The simplest proteins are the protamines found in fish sperms. The conjugate proteins have the protein molecule united with some molecule or molecules other than a salt.

The conjugate proteins include the nucleoproteins in which nucleic acid is united with the protein, glycoproteins which contain a carbohydrate, phosphoproteins, hemoglobins where hematin is the combining form, and lecithoproteins. This group of the proteins is subdivided into many distinct substances, the discussion of which belongs to organic chemistry.

The third class of proteins is the derived proteins, which should not be confused with the natural proteins existing as simple and conjugate proteins. These are all derived through digestion. As the protein molecule is thus transformed and becomes soluble certain stages are recognized, and each of these gives definite chemical reactions that enable the expert to recognize six classes.

¹ For the significance of these percentages consult Chapter I, Chittenden, *Nutrition of Man*.

Proteins are so complex chemically that their formula is not accurately known; one writer in order to show the complexity of egg albumen has proposed the following empirical formula: $C_{204}H_{322}N_{52}O_{66}S_2$.

Proteins are non-diffusible, are coagulated by heat and are usually called nitrogenous foods. Explaining their use to the frog in terms of what is known about higher animals, it can be said that proteins perform the definite work of renewing the wornout and exhausted parts of the organs. In fact no other kind of food can do just this work nor does any other class of food stand in such close relation to the vital processes of the frog. Oxygen, nitrogen and all of the other elements exist in the air, but they cannot be used in the repair of the organs because they are not combined into protein molecules.

Carbohydrates.—The word carbohydrate refers to a group of bodies made in the cells of plants. Carbohydrates contain carbon, hydrogen and oxygen; with the hydrogen and oxygen combined in the same proportions as water, H_2O , this is shown in the starch molecule, $C_6H_{10}O_5$, where one may expect to find about 44.4 per cent. of carbon, 6.2 per cent. of hydrogen and 49.4 per cent. of oxygen. The carbohydrates are classified as monosaccharids, which contain the most important simple sugars, such as dextrose ($C_6H_{12}O_6$); d'saccharids, such as maltose from cane-sugar and lactose from milk-sugar ($C_{12}H_{22}O_{11}$); and polysaccharids, of which starch, dextrin and cellulose are best known ($C_6H_{10}O_5$)_n.

Fats.—Fats are formed of the same elements as carbohydrates, but there is less oxygen in the fat molecule. Because of the absence of nitrogen these last two classes of foods are called non-nitrogenous foods. Fats contain about the following proportions: Carbon, 76.5 per cent.; hydrogen, 11.9 per cent.; oxygen, 11.5 per cent.

Fats are widely distributed in organic nature. They are stored in the seeds, roots or fruit of plants, and all animal tissues contain a varying amount, being especially abundant in bone, marrow and adipose tissue.

Some of the common animal fats are stearin in beef suet and butyryn in butter. Most fat is a mixture of several individual fats. "Thus the ordinary mutton fat contains more tristearin and less triolein than pork fat." Human fat contains from 67 per cent. to 85 per cent. of triolein.

The non-nitrogenous foods are easily diffusible and serve as the natural fuel foodstuffs of the body. They cannot serve for renewing the exhausted parts of an organism. The frog does not secure a large

amount of carbohydrate except as vegetable matter is eaten, but it does get plenty of fat associated with the lean meat of insects, tadpoles, frogs, etc.

Digestion.—It is easily recognized that the food of the frog after it has been eaten is not within his body proper but simply in the hollow digestive tube. It is entirely possible for food to pass through the frog and not yield any energy simply because it has not entered into the body of the frog. Most of the foods have to undergo important changes before they pass through the walls of the digestive tube. These changes are induced by what are called digestive secretions. A secretion is defined in biology as follows: *Any substance which is the product of living cells and serves some useful purpose in the economy of organisms may be called a secretion.* In this sense every secretion has been a part of the living substance of some part of an organism and is usually produced in what are known as glands, such as the liver or pancreas, in other instances the gland is a small part of the inner wall of the stomach. The ovaries and spermaries are both glands, although their secretion takes the form of cells, ova and sperms instead of a fluid.

The glands of the frog are divided into those that have a duct which carries the secretion into some specific cavity, such as the bile duct, through which the bile flows into the intestine, and into ductless glands, such as the spleen, adrenal and hypophysis (page 28). These ductless glands, and there are several others, are just as truly glands as the liver or pancreas, but they all pour their secretions into the blood, and for this reason are spoken of as *internal secretions*. Some writers use the general term, *hormone*, for the secretion of an internal gland. We are just beginning to discover the importance of the several hormones in the normal growth and physiology of all animals.

The digestive secretions are known as enzymes, a term coined by Kuhne, in 1878, because of the nature of the changes that they are capable of producing in the food. In chemical terms we describe *an enzyme*¹ as a *catalytic agent formed in the living organism*. Such bodies initiate and accelerate chemical changes in another body without undergoing any change themselves. Fischer speaks of the specific action of enzymes, that is, the capacity of digestive enzymes to attack one substance and not another which may even be closely related. Halliburton illustrates the work of an enzyme by saying:

¹ What are enzymes? Horwitz: The Scientific Monthly, March, 1918.

"We may roughly compare enzyme to an ill-disposed person who comes into a roomful of good-natured people and who succeeds in setting them all by the ears. He has produced a change in them by his mere presence without undergoing any change himself. He is, moreover, able to repeat the process over and over again in fresh roomfuls *ad infinitum*."

The stomach of the frog contains many glands that produce gastric juice which consists of a small amount of hydrochloric acid and the enzyme, pepsin (Fig. 14). Pepsin acts on the proteins only and transforms them into a substance that will pass through the walls of the digestive tube. It is difficult to understand how this change is brought about and especially the extent of the changes which take place in the protein molecule up to the time that it takes the

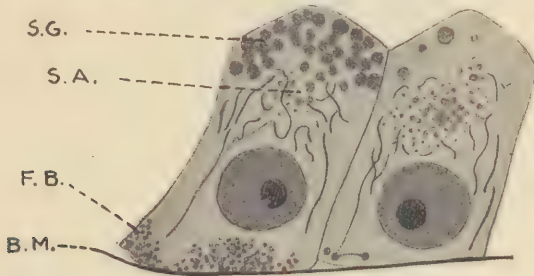


FIG. 13.—Two cells from the pancreas of the frog; the one on the right shows numerous secretion granules, *S.G.*, which are believed to contain the enzymes of the pancreas. Additional granules are in the process of formation in the area indicated by *S.A.*, the secretion area. The cell on the left has discharged its secretion granules. *F.B.*, fat bodies of uncertain function. *B.M.*, basement membrane. There are other structures believed to be associated with secretion and the whole problem is far from settled. (From Saguchi.)

form of an amino-acid, for the pepsin is the same as when it was set free from the glands and poured into the stomach, but the molecule of protein has undergone a great change, the details of which are too technical for this work. The action of an enzyme on a food is known as fermentation, and since pepsin acts just as readily in a test-tube as in the stomach, *i. e.*, apart from the living gland that produced it, it is called an unorganized or non-living ferment. All of the digestive ferments are unorganized.

When the gastric enzyme has done its work the residue of undigested proteins, the fats and the carbohydrates pass into the intestine to come in contact with the alkaline secretions of the pancreas and liver where the process of digestion is completed. The pancreas of the frog has the faculty of secreting three distinct enzymes,

each specific in its action. These are trypsin, which converts proteins into amino-acids, amylpsin, which changes starches into sugars, and steapsin, which causes a splitting of fats into fatty acids. The bile assists in emulsifying the fats, *i. e.*, the fat becomes transformed into minute globules, which gives a milky appearance to the liquid. The several digestive enzymes act as accelerating agents merely, for all of these changes would eventually take place if given sufficient time. The speed with which these changes take place is much greater under the influence of the living cells than when they occur in a test-tube, for example. Mathews says: "Living matter is hence

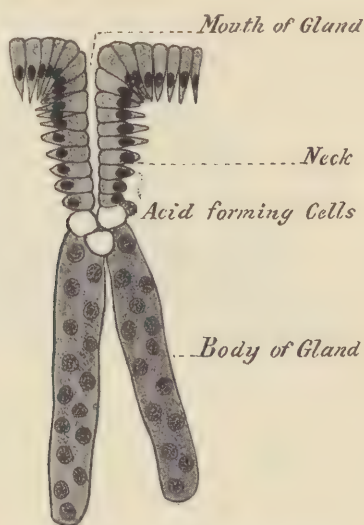


FIG. 14.—Gastric gland of frog.

peculiar in the speed with which these hydrolytic, oxidative, reduction or condensation reactions occur in it; and it owes this property to various substances, catalytic agents or enzymes, found in it everywhere." (*Physiol. Chem.*, p. 10.)

The digested food is absorbed through the internal layer of the digestive tube (Fig. 20) and passes into the blood, where its course will be followed in the next chapter. The use of the word absorb does not convey an accurate idea of just what is meant by the process. In this passing of food through an animal membrane, the lining epithelium of the digestive walls, there is the physical process of osmosis, to which must be added probably some action on the part

of the living protoplasm of these cells. Just what this action is cannot be fully stated (Fig. 15).

The fate of the digestive secretions illustrates one of the strange wastes of Nature. After the several foods have been rendered soluble and diffusible, in other words, digested, we are led to believe that there is just as much of the several enzymes as when the



FIG. 15.—Epithelium of frog, showing fat globules passing through the living epithelial cells of the intestine. (After Krehl.)

digestive process began. The body of the frog absorbs but a small portion of them and the remainder pass from the body with the indigestible parts of the food. If Nature provided some way of collecting and using these secretions again, there would be a large economy in the life of every animal. The need for food and the principles of digestion are common to all forms of life.

CHAPTER IV.

CIRCULATION—METABOLISM.

Heart.—The blood of the frog follows well-defined routes as it travels to all parts of the body, and in this particular the frog belongs to the higher rather than to the lower class of animals. These routes of travel for the blood are the arteries, which carry it from the heart, and the veins, which return it to the heart. The heart is a most interesting organ because of its origin and work. Could you observe the heart as it first begins to beat and force blood along in the embryonic bloodvessels, you would not recognize in it the adult, conical, compact heart but rather an elongated branched structure which passes through a series of complicated changes before the adult structure is reached. This wonderful propelling organ for the blood is a gradual growth, and it took Nature a long time to evolve it. The work of the heart is to force the blood continually through the bloodvessels. It contracts slowly as compared with the human heart, but evenly and uniformly during the active season; while during hibernation the beats are feeble and slow. The fact that a structure exists which works regularly day and night, week after week, year after year, and only rests seconds or fractions of a second at a time, is a constant source of wonder.

Some appreciation of this intrinsic property of the cells of the heart to contract is gained from experimental studies upon the embryonic heart. When some of these cells are isolated in a culture medium suitable for their growth they grow and eventually unite in various patterns. After union the cells begin to beat in rhythm, although entirely detached from the embryo (Fig. 16).

The frog's heart is situated just anterior and ventral to the liver. It is surrounded by a thin membrane, the pericardium. The heart is made up of three parts: (1) The conical ventricle, with the point directed posteriorly; (2) the two auricles, right and left, which are in front of the ventricle. A thin membrane divides the two auricles into separate chambers. The right auricle receives venous blood from the body and the left auricle oxygenated blood from the lungs. Both auricles empty their blood into the single ventricle, which

in turn contracts and fills the arteries. As the blood leaves the ventricles it enters the large bulbus arteriosus, which forms two



FIG. 16.—“Series of single heart-muscle cells which have been observed to grow, beat separately, unite with one another and finally beat in unison.” (Redrawn from Tower and Herm, *Am. Mus. Jour.*, 1916, xvi, 473.)

branches that give rise to the aortic arches (Fig. 1). The details of the heart, arteries and veins should be worked out in the laboratory.

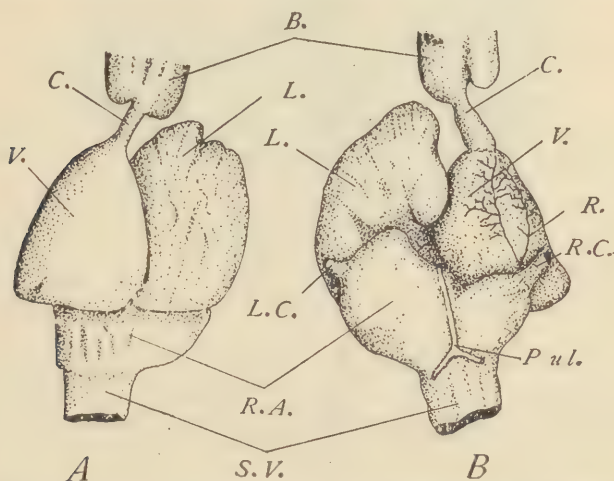


FIG. 17.—The heart of *Cryptobranchus*. A., ventral aspect; B., dorsal aspect. B., bulbus arteriosus; C., conus arteriosus; L., left auricle; L.C., left anterior vena cava; Pul., pulmonary vessels; R., coronary vessels; R.C., right anterior vena cava; S.V., sinus venosus; V., ventricle. (Reese.)

Blood.—The blood of the frog consists of corpuscles and plasma. There are three kinds of corpuscles: (1) The red, which are oval in

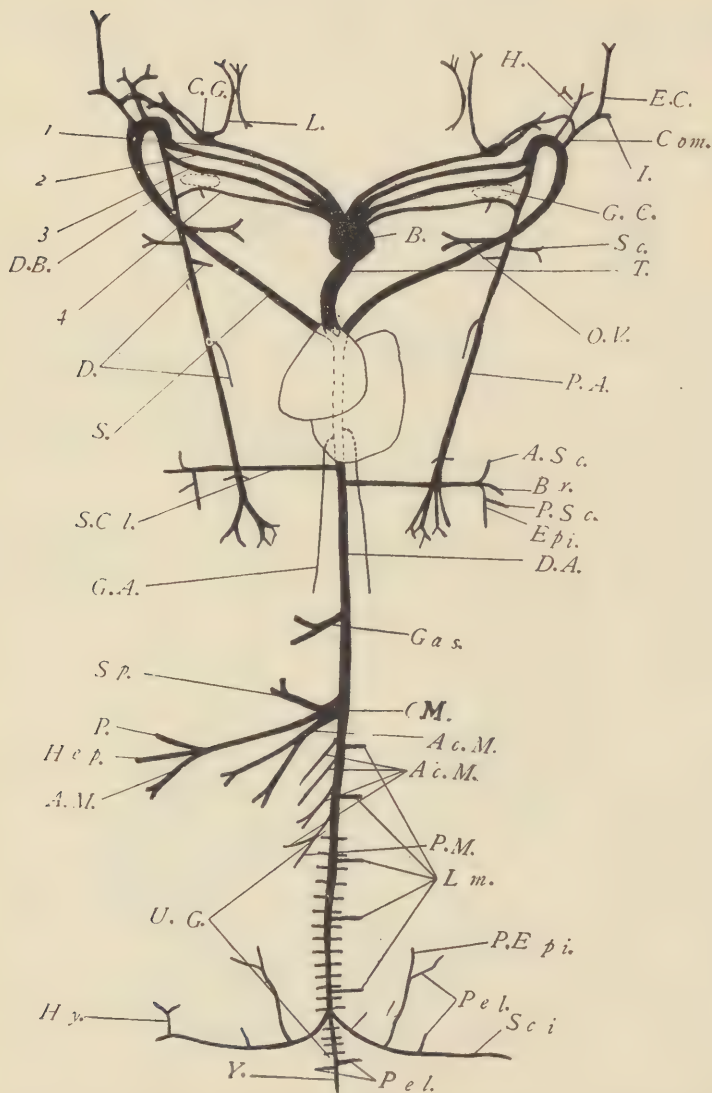


FIG. 18.—The arterial system of *Cryptobranchus*, ventral aspect. A.M., anterior mesenteric; Ac.M., accessory mesenteric; A.Sc., anterior scapular; B., bulbus arteriosus; Br., brachial; C.G., carotid gland; C.M., celiacomesenteric; Com., ramus communicans; D., to dorsal region near lungs; D.A., dorsal aorta; D.B., ductus Botalli; E.C., external carotid; Epi., epigastric; G.A., anterior genitals; Gas., gastric; G.C., gill cleft; H., hyoid; Hep., hepatic; Hy., hypogastric; I., internal carotid; L., lingual; Lm., lumbar; O.V., occipitovertebral; P., pancreatic; P.A., pulmonary; Pel., pelvic; P.Epi., posterior epigastric; P.M., posterior mesenteric; P.Sc., posterior scapular; Sc., scapular; Sci., sciatic; S.Cl., subclavian; Sp., splenic; T., conus arteriosus; U.G., urogenitals; Y., caudal; 1, 2, 3, 4, first to fourth branchial arches. (Reese.)

outline and contain hemoglobin. The work of the hemoglobin is to carry the oxygen from the organs of respiration to all parts of the body. (2) The white corpuscles, smaller than the red and irregular in shape. They are factors in the clotting of blood (Fig. 19), the destruction of foreign bodies, such as disease germs, and the removal of degenerating parts. The white blood cells, or phagocytes, change their form much as an ameba does, and consequently have the power of independent locomotion, so that they pass through the thin walls of the capillaries and out into the spaces between cells, and are found in all parts of the frog. As they thus migrate around in the body minute foreign particles, such as bacteria, are met with

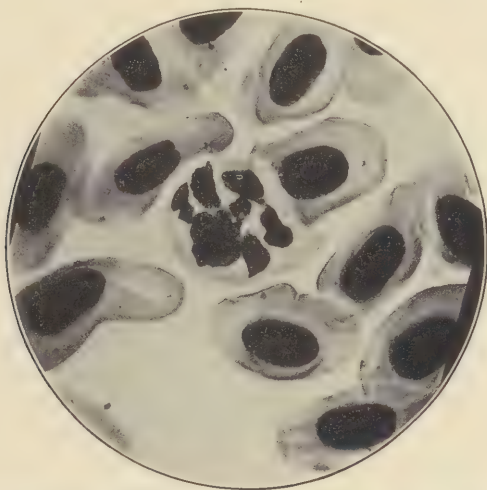


FIG. 19. — Photomicrograph of blood of necturus. Compare the oval nuclei in the red corpuscles with the polymorphic nucleus of the white corpuscle in center of figure.

and eaten (phagocytosis). Their method of eating will be better understood after the study of the protozoa, where a similar method of eating is the usual process. These white cells also help to remove broken bits of tissue, as in the removal of the degenerating tail. (3) The spindle-shaped corpuscles are colorless except during the spring when they acquire hemoglobin and are transformed into red blood corpuscles. They are smaller than the true red corpuscles and may change their shape somewhat. Besides forming new red cells they assist in the clotting of the blood. The blood corpuscles wear out like the other parts of the body and have to be renewed. The marrow of the bones is one of the most important sources for the

origin of new blood corpuscles. The plasma of the blood is straw-colored or else colorless in appearance. It contains the various transformed foods, water and salts, as well as the waste products of the body; hence its chemical composition varies from day to day and from season to season, being influenced largely by the animal's amount of activity and its food supply.

The lymphatic system does not occupy definite lymph vessels but consists of several large, irregular-shaped lymph spaces. Some of these can be easily dissected and their boundaries determined as the skin is removed. These subcutaneous spaces are separated by thin septa of connective tissue. The colorless lymph flows into the blood through the four lymph hearts. A pair dorsal to the anal opening can easily be seen beating in the living or recently killed frog.

Respiration.—The carrying of food to all parts of the body is but one work which the blood does. A second is its relation to respiration; the presence of hemoglobin in the red blood corpuscles is for the sole purpose of uniting chemically with the oxygen as the blood flows through the lungs or close to the skin. The oxygen becomes loosely combined with the hemoglobin, with which it remains until a place in the body is reached where there is a scarcity of oxygen, then the oxygen is released from the hemoglobin and passes through the walls of the capillaries to take part in the vital activities of that region. When the oxygen first unites with the hemoglobin it gives it a bright red color which darkens as the oxygen participates in the vital processes. Coincident with this taking of oxygen to all parts of the body is the carrying away by the plasma and hemoglobin of a waste substance known as carbon dioxide. The carbon dioxide is carried to the lungs or skin, where it leaves the body of the frog, passing into the air. Thus the frog is continually taking oxygen from the air and giving off a waste substance, carbon dioxide, to the air. If certain other agencies were not at work we could easily believe that after a time the oxygen content of the air would become so much reduced that breathing for all animals would become difficult or impossible. In applying the term waste to carbon dioxide a definite meaning is given in biology. *Waste substances are such as have once been a part of the living body and are produced as a result of some expenditure by the living organism. In this sense waste and excretion have the same meaning.*

The frog, like all living things (except certain bacteria), uses this oxygen in a definite manner, which is characterized as one of the fundamental vital processes. Lavoisier, in 1792, pointed out that

the use of oxygen in respiration was a chemical process. That heat was produced by living things and ceased with their death was known from the earliest times. But not until the discovery of oxygen in 1771 was it possible to understand how this heat was formed in living things. This suggestion of Lavoisier is really the beginning of the modern physiological study of biology, because his suggestion showed that chemical elements and compounds behave in a definite manner in living things, thus furnishing a scientific starting-point for such explanations. The value of this scientific point of view in this connection is well illustrated by the following: Oxygen exists in the atmosphere as O_2 molecular oxygen and in very small quantities as O_3 ozone. When these two chemical bodies are brought in contact with living protoplasm more heat is furnished by O_3 than O_2 . If this difference is computed there are found to be 32,000 more energy units (calories). At first thought this seems to be a very great difference, but if an equal amount of coal is first burned with O_2 and the same amount could be burned with O_3 there would result approximately 20 per cent. more heat. The percentage of differences is probably much higher in living protoplasm but not as great as one would infer from the figures, 32,000. The important fact to be retained from this illustration is that heat is constantly being given off as molecules undergo simplification in the several aspects of metabolism. On the other hand we must assume that heat is taken up by these same chemical changes in metabolism, as, for example, when food-products are gradually built into complex bodies similar to protoplasm which occurs just before food becomes protoplasm.

In any discussion of respiration it must be remembered that respiration is a vital process that takes place within the living protoplasm, and as the oxygen reacts on carbon, energy in the form of heat is supplied. This is known as oxidation.

Metabolism.—The nature of the several excretions and the character of the food in the blood tell much concerning the vital processes. More can be learned in an advanced course in physiology, but even there a great deal is not understood. There seem to be a number of constructive or up-building agencies, in the form of internal enzymes, which serve to make the combinations of the nitrogenous and non-nitrogenous molecules more like those that exist in living substance, but there is still a wide difference between the two, and science has not yet discovered just how the food becomes living. How long the transformed food remains a part of the living substance is a matter of conjecture. The changes which initiate

the breaking down of the living substance and the formation of waste products are also unknown, yet the two processes are taking place all the time in the body of the frog, the one in the nature



FIG. 20.—Johannes Müller, 1801-1858. The most famous physiologist of his time. He introduced the comparative study of physiology and gave special attention to the physiology of organs. His work marks an epoch in the development of the science of biology. (From Loey's *Biology and its Makers*.)

of construction or up-building and the other destruction or tearing down. To cover these two widely different processes in the body the general term metabolism is used. "*Metabolism designates that complex of chemical changes in living organisms which constitute their life, the changes by which their food is assimilated and becomes a part of them, the changes which it undergoes while it shares their life, and finally those by which it is returned to the condition of inanimate matter.* Gathered together under this one phrase are some of the most intricate and inaccessible of natural phenomena." (Chittenden.) The single word metabolism is used to indicate one of the distinguishing characters of all organisms. In using the term in this way it is understood to include the changes indicated in the definition; and while these are many and divergent, yet they are a part of one vital process. Thus used metabolism serves to mark off sharply the activities of living substance from all forms of activity in non-living matter and is a distinguishing feature of living matter only.

Hibernation and starvation are two closely allied phenomena. In both instances the organism sustains itself by utilizing energy stored within the body. Until the discovery of internal enzymes little was known concerning the physiology of these conditions. It has been known for some time that the muscles of the frog become lighter during hibernation, but what the agent was that enabled the frog to withdraw energy from muscles was not understood. The writer has experimented with some fish and has been able to keep one without food for twenty months. The result was that the muscles became very much reduced and the fish was hardly able to move. A similar condition exists in human beings in the case of a fever or tuberculosis. The body becomes very much lighter and emaciated. What has become of all of the energy stored in the muscles in all these illustrations and how has it been utilized? The most widely accepted theory at present is that the internal enzymes may reverse their action when there is a demand for food-energy and attack the muscles. This is known as the reversibility of internal enzymes. In these cases of hibernation, starvation and emaciation from sickness it is probable that the internal enzymes are the agents that release the food energy that exists as muscle which thus freed is carried by the blood to such parts of the body as demand food to keep the organism living. A chemical examination of the blood of a starved fish and of one recently caught revealed the fact that there was about the same amount of food products in each.

Metabolic Water.—That water is necessary to life has been known for a long time. During development it is the most abundant constituent, ranging from about 40 per cent. to nearly 100 per cent. This demand for water enters into the very life of the cells and is satisfied from imbibed water and from metabolic changes in the food. The imbibed water serves to dissolve nutrients, to act as a medium for their distribution, to remove injurious waste products and to influence temperature to some extent by the amount of evaporation.¹

The metabolic water is chiefly derived from the oxidation of nutrients. The carbohydrates, fats and proteins all contain hydrogen, and their complete oxidation as they are built up into living protoplasm or take part in the several vital processes produces a certain amount of water. "Thus 100 parts of cellulose or starch ($C_6H_{10}H_5$)_n, containing 6.17 per cent. of hydrogen, give 55.5 parts of water. Most fats yield more than their weight of water, while proteins when completely oxidized give from 60 to 65 per cent. of water. (Babcock.) The several nutrients are oxidized in the cell protoplasm. Here the formation of water in the protoplasm gradually and continuously renders the nutrient solution within of less density than that without. Such a difference in concentration ensures a constant movement by osmosis toward the points where foods are needed.

The rate of oxidation is greater in animal cells than in plants, consequently there is a greater amount of waste in animals. This is especially the case with soluble products arising from protein metabolism. These are excreted through the kidneys in the urine in the form of urea in fishes, amphibia and mammals, while in birds, reptiles and insects most of the nitrogen waste is in the form of uric acid or its ammonia salt. These are practically insoluble in the body, so that the need for water in such animals is much less because the uric acid is not as poisonous nor its accumulation as dangerous.

In all animals the protoplasmic need for water is largely supplied by the metabolic water, and during hibernation the metabolic water is sufficient for all the vital needs. In such cases it is derived from the food energy stored in muscles and fat. In a similar way insects that live upon air-dried food and desert animals are able to supply their bodies with the requisite amount of water.

In this chapter it has been shown how certain organs work and the importance of this work to the organism as a whole. This is the period of Müller in the growth of biology.

¹ Babcock, S.: *Metabolic Water: Its Production and Role in Vital Phenomena.*

CHAPTER V.

TISSUES AND CELLS OF THE FROG.

Histology.—Anatomy or gross morphology enables one to learn much about the shapes and relations of most of the organs of the frog but it tells very little about the parts of the organs themselves. In the analysis of the minute structure of an organ the method is essentially the same as in the study of anatomy except that one must employ some magnifying instrument to enlarge the minute parts in the organ. The compound microscope is used for this purpose. The preparation of an organ for this minute analysis illustrates how biology utilizes the science of chemistry, for without the chemical information now available the details of an organ as well as many other important biological facts would be unknown. The general term histology is used for both the preparation of an organ and its subsequent analysis by the aid of the microscope. In the preparation of the organ for histological study several distinct chemical processes are employed, usually in the following order: (1) Killing and fixing all of the parts of the organ in as normal a relation and shape as possible. (2) Hardening the many parts so that they will retain their characteristic outline, etc. (3) The staining of all the parts so as to differentiate them as a result of their different reactions to stain. It requires much skill to be able to secure the best possible results in the use of the many stains now employed. (4) The parts of the organ must be cut into thin, nearly transparent sections if the microscope is to be employed in studying them. Each of these several processes requires much detailed technical work, each step of which must be accurately done or the result is a failure. The science of histology is very technical, although fundamental to the study of embryology, pathology and bacteriology. The present chapter aims to serve as an introduction to the histological analysis of an organ.

Histology of Intestine or Stomach.—When the microscopic slide of the stomach or intestine was studied it was an easy task to recognize three general layers. Each layer was characterized by having many very small structures known as cells. These cells in the inner layer were elongated and arranged in rows. In a similar

manner the shape and arrangement of the cells in the other layers were made out (Fig. 21). These different layers are known as tissues, and from a morphological standpoint a tissue is defined as a group of similar cells, similar in shape and arrangement; but this is only part of the definition, for these similar cells must do a similar work for the organ. A tissue is therefore usually defined as a *group of similar cells having a similar function*. The definition should always be recognized as having these two aspects. All the organs of the frog are made up of several tissues, and what is true of the frog is true of all complex animals, so that an organ is defined as a group of tissues united in order to do a given work for the organism. Bichat advanced our knowledge of living things by his famous studies upon the composition and work of tissues.

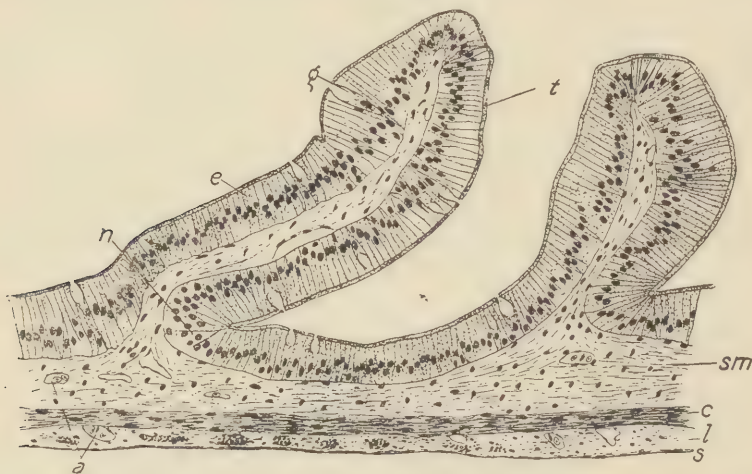


FIG. 21.—Transverse section through the intestinal wall of *Cryptobranchus* to show the details of two longitudinal folds. *a*, bloodvessels; *c*, circular muscle layer; *e*, columnar epithelium forming the layer; *g*, goblet cells; *l*, longitudinal muscle layer; *n*, group of young cells; *s*, serosa; *sm*, submucosa; *t*, top-plate or striated border. (Reese.)

Tissues.—In all of the higher organisms the body consists of a number of distinct tissues which have been arranged into four classes based on their function and intimate structure. These are (1) epithelial; (2) connective or supporting; (3) muscular; (4) nervous.

1. *Epithelial Tissues.*—The epithelial tissues are the oldest and the first to appear in the embryonic development. They have undergone but little modification in order to perform their several functions. These tissues are found in the skin of the frog, lining the mouth and entire digestive canal, lining the lungs and ducts of

the entire excretory and reproductive systems. They also constitute the glandular cells in the liver, pancreas, kidneys, ovaries and testes of the frog. Their most important work is to form a protective covering to surfaces, both exterior and interior, to avoid drying, to act as a buffer against mechanical injury, and to prevent infection by disease germs. Their very position makes them the most important structures in secretion and excretion in glands (Figs. 23 to 25) and in receiving stimuli from the external world. Epithelial tissue is subdivided into (a) flattened or squamous (Fig. 22); (b) columnar (Fig. 24); (c) ciliated (Fig. 23). Epithelial tissue has a small amount of intercellular substance. The glands in the frog consist of two general classes, defined as unicellular and multicellular. In the unicellular gland a single epithelial cell takes on the function of producing a secretion (Figs. 23 and 24). Multicellular glands involve a number of epithelial cells that may undergo considerable change in shape. The two main kinds of multicellular glands are the tubular and acinous (Fig. 25).

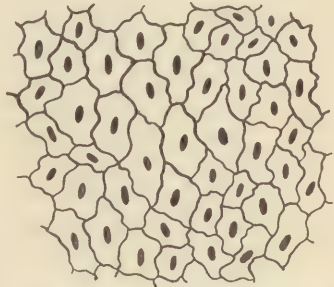


FIG. 22.—Squamous epithelium from the mesentery of the frog.



FIG. 23.—Ciliated epithelial cells from the roof of the mouth of the frog. Note the two unicellular gland cells packed with coarse granules.



FIG. 24.—Columnar cells from the lining epithelium of the small intestine of the frog. Two unicellular gland cells are also shown.

2. *Connective Tissues*.—Connective tissues embrace a large number of tissues whose main function is to bind the parts of the organism together. They are found in the deep parts of the body and gain their importance chiefly through the intercellular substances. One

of their primary functions is to fill the spaces between organs. The four following kinds of connective tissue are recognized: (a) fibrous; (b) adipose; (c) cartilage (Fig. 26); (d) bone (Fig. 27). By some the

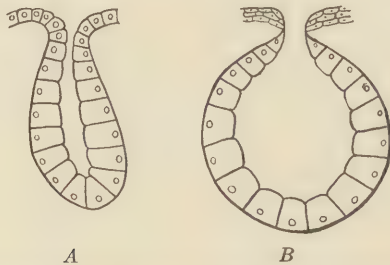


FIG. 25.—A, tubular gland from tongue of frog; B, acinous gland from skin of frog.

blood is regarded as a modified form of connective tissue, the plasma being regarded as the intercellular substance and the corpuscles the living part of the tissue; while others regard the blood as simply a nutritive fluid of which there are two kinds: (a) the blood proper and (b) the lymph.

3. *Muscular Tissues*.—Muscle cells are recognized apart

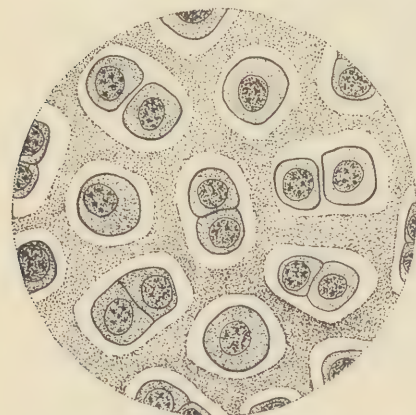


FIG. 26.—Cartilage from the sternum of the frog. Notice the large amount of intercellular substance shown by "stippling," which is one of the important points to notice.

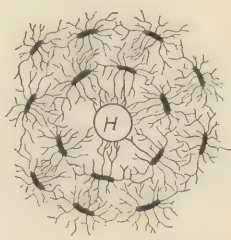


FIG. 27.—Diagram of finer structure of bone. H, Haversian canal. The intercellular substance is represented by the uncolored areas between the oval black area and their branches.

from all other cells in the frog by the specialization that has taken place in the cytoplasm. As is well known, muscles are divided into voluntary and involuntary. The cytoplasm in the cells of each kind becomes modified so that there results a rapid contraction in

the voluntary and a slow contraction in the involuntary muscles. The involuntary muscle cell has undergone but a small amount of change (Fig. 28); while the voluntary cell is greatly elongated, has special bodies which give a cross-striated appearance and there is more than one nucleus for each cell (Fig. 29). The term sarcoplasm is given to the cytoplasm of muscle cells. Muscular tissues are also sharply distinguished from all other tissues by their function. Muscle cells work by shortening in length and correspondingly increasing in diameter. This property of contraction is an intensification of the fundamental power of movement in protoplasm.

4. *Nervous Tissues*.—Nervous tissue serves to conduct stimuli and as such must connect the sensory surfaces with the central nervous system, and also the muscles with the coördinating center. The cell elements are ganglion cells and their nerve fibers. The ganglion cells are confined to the central nervous system or to small ganglia just outside this system. The



FIG. 28.—Involuntary muscle cells from the stomach of a frog.

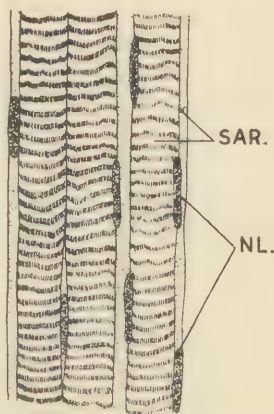


FIG. 29.—Voluntary muscle cells from the fish *Amia calva*. Notice the narrow layer of unmodified cytoplasm. *NL.*, nucleus; *SAR.*, sarcoplasm.

nerve fibers are naked and sheathed. (Discussed in detail in Chapter VI.)

The Cell.—All tissues are defined in terms of the cell, which is the smallest unit of structure in biology. While the cell is very small it is perplexingly complex. In the last analysis most of the biological problems are problems of the cells, and for this reason a clear understanding of its parts is necessary. The histological study of the intestine, as well as Figs. 22 to 29, shows that cells vary widely in shape. In some instances the shape is obviously the result of the pressure brought to bear upon the tissue, as in columnar cells; while in others there is a widely branching condition which suggests that the shape may be influenced by the nature of the tissue. The spherical ovum is probably the typical shape for a cell and is regarded as the most

primitive form of cell (Fig. 44). The parts of a cell may be described by taking a typical cell in the non-dividing stage. This stage is frequently referred to as the "resting stage," but a cell is always metabolically active and irregularly reproductively active, so that the term resting stage as applied to a cell is misleading. The term cell was coined by Robert Hooke in 1665. While working on the vegetal tissue cork he reported that it was composed of "little boxes or cells distinct from one another." What he saw was but the outer limiting membrane, all of the living substance being absent in cork.

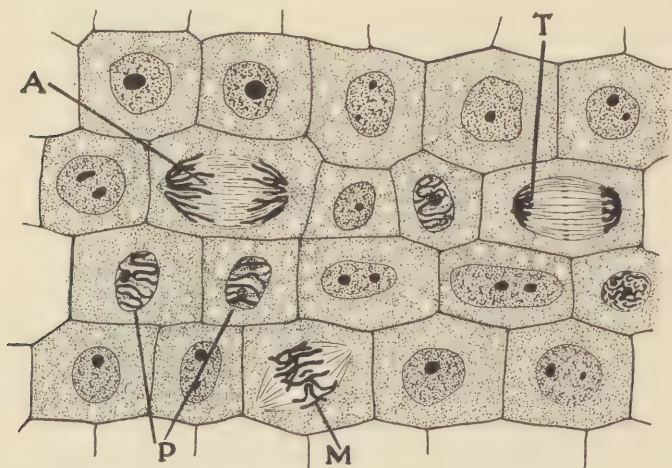


FIG. 30.—Cells in the growing onion-tip. Compare the nucleus in the non-dividing cells with the nucleus in the dividing cells. A, anaphase stage in dividing nucleus; M, metaphase stage; P, prophase stage; T, telophase stage.

Cell Theory.—In 1838 appeared the memorable contribution of Schleiden and Schwann, who declared, as a result of their researches, that every plant and animal was composed of cells. Many other investigators verified their conclusions until now their names are always associated with one of the few great generalizations in biology, the cell theory of Schleiden and Schwann. This doctrine implies three propositions: (1) That all organisms can structurally be resolved into cell units no matter how complex or how simple; (2) that every organism begins life as a single cell which by growth and differentiation gradually assumes the adult form; (3) that the functions or work of all organisms can be interpreted in terms of the activity of its individual cells. "No other biological generalization,"

says Professor Wilson, "save only the theory of organic evolution, has brought so many apparently diverse phenomena under a common point of view or has accomplished more for the unification of knowledge." The living substance within the cell was named *protoplasm* by Hugo von Mohl (1846), although the term was earlier used by Purkinje (1840) to designate the formative material of young embryos. Leydig and Max Schultze, about 1860, defined a cell as "a mass of protoplasm containing a nucleus."

Protoplasm.—The protoplasm of a cell consists of (1) a *nucleus* (Fig. 30), first described by Fontana in 1871 and regarded as a normal element of the cell by Robert Brown in 1883; (2) the *cytoplasm*, a term formulated by Kölliker in 1863, which by usage has come to be applied to the living substance of the cell body other than the nuclear, although this was not its first meaning; (3) the usual presence of a cell membrane. The nucleus is usually of rounded form and embedded in the cytoplasm. There is a definite nuclear membrane in most instances when the nucleus is not dividing. Within the nucleus there are two classes of bodies: (a) chromatin network; (b) achromatic substances. The one or more rounded nucleoli belong to the first class. The cytoplasm presents a variety of appearances largely depending upon the kind of cell being studied and the stains employed. It is to be regarded as a chemical mixture in which the elements assume various forms. The nucleus and cytoplasm constitute a unit of structure. The subject of cells will receive more extended consideration in the section of this book devoted to the Biology of Cells.

The discovery of the cell and the proper emphasis of the importance of protoplasm to vital processes brings the historic development of biology down to modern times. The remaining discussions of biological phenomena in this book will start from the cell, the modern point of view.

CHAPTER VI.

NERVOUS SYSTEM OF THE FROG.

Nervous System.—The nervous system is composed of three well-known divisions: the central, peripheral and sympathetic. The central consists of the brain and spinal cord, which is protected by the skull and vertebræ and two membranes, the dura and pia mater. To the peripheral division belong all of the nerves arising from the brain, termed the cranial nerves and the spinal nerves. These nerves pass to the skin, sense organs and muscles. There are two main trunks of the sympathetic system which lie just beneath the spinal column in the cœlomic cavity. As these branches cross the spinal nerves there is formed a connection with a slight ganglionic enlargement (Fig. 31). The sympathetic nerves branch profusely in connection with the viscera, forming several plexuses (solar, urogenital, etc.). The brain and spinal cord form the most important of these three divisions, for to it all general stimulations report and from it all commands are issued.

The gross study of this region reveals a short and somewhat flattened spinal cord with two swellings; the first opposite the arms and the second opposite the hip region. Fig. 31 explains why these two regions are enlarged; from each large nerves pass off. Posteriorly the spinal cord ends in a small point (the *filum terminale*). Anteriorly the spinal cord merges into the brain without any sharp demarcation. The brain is subdivided into the following, beginning from behind: the medulla oblongata, the cerebellum, the midbrain, the thalamencephalon, the cerebral hemispheres and the olfactory lobes (Figs. 32 and 33).

The medulla is recognized by the large opening on the dorsal side, the fourth ventricle. This opening is roofed by a non-nervous tissue richly supplied with bloodvessels and termed the posterior choroid plexus (*mtplx.*, Fig. 32). From the sides of the medulla arise five pairs of cranial nerves and from its floor one pair of eye-muscle nerves. The nerves from this short and insignificant appearing section of the brain regulate the heart in part, respiration, taste, hearing and the general muscles and special senses of the head other than seeing.

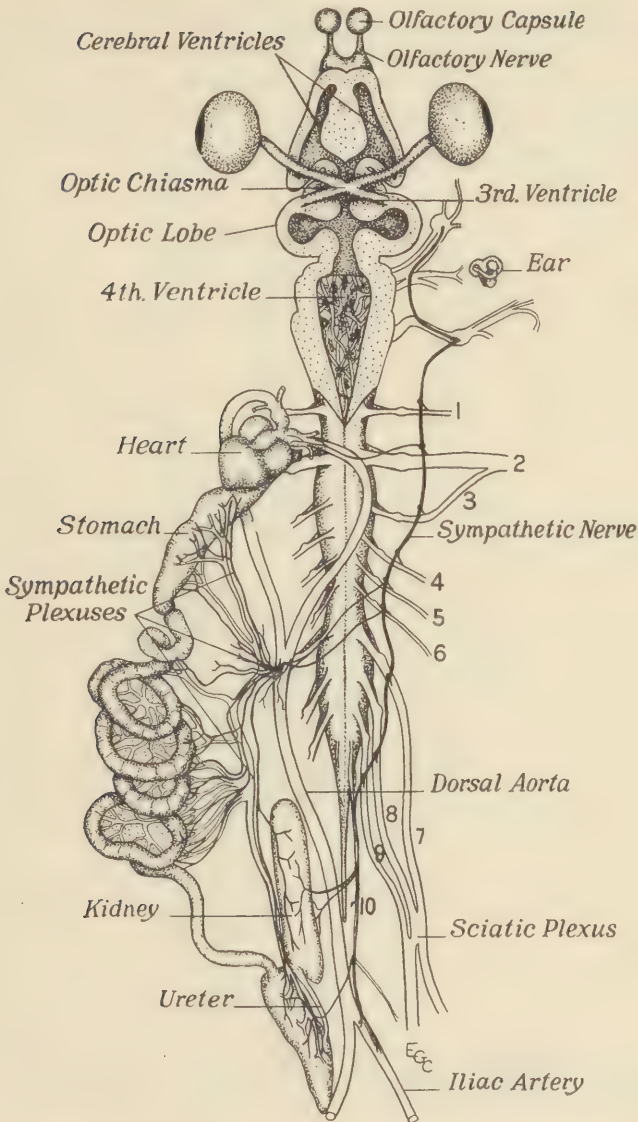


FIG. 31.—Ventral view of nervous system of the toad. The sympathetic nervous system is drawn in solid black lines. Note its relation to the spinal nerves and visceral organs. The floor of the brain has been removed so as to show the ventricles of the brain. Observe the relation that each of the sense organs has to the brain. The eighth nerve is connected with the ear, which is closer to the brain than in the drawing.

Immediately in front of the medulla is the small transverse fold, the cerebellum, which becomes much larger in the higher vertebrates. The roots of one pair of eye-muscle nerves are located in it. The dorsal surface of the midbrain is made prominent by the large oval masses (the optic lobes rudimentary in *Necturus*, Fig. 32).

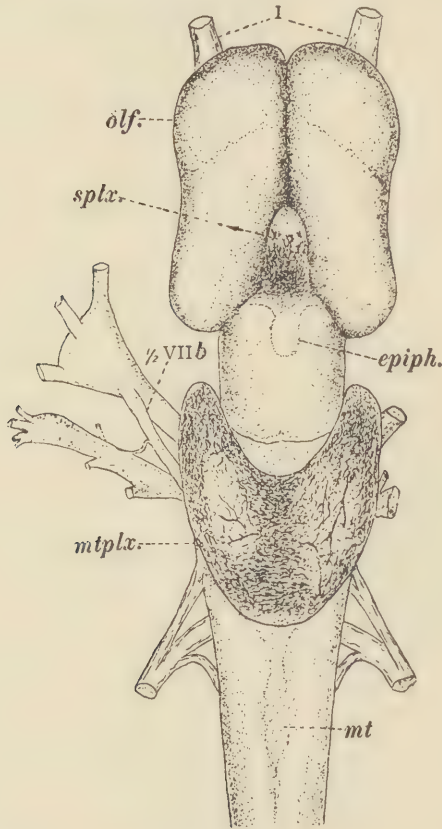


FIG. 32.—The brain of *Necturus maculatus*, dorsal aspect. $\times 5.4$. *olf.*, olfactory portion of cerebral hemisphere; *splx.*, supraplexus; *epiph.*, epiphysis; *mtplx.*, metaplexus; *mt*, metatela. (Kingsbury.)

The shortest and most inconspicuous section of the brain is the thalamencephalon. Its roof is non-nervous and contains numerous bloodvessels, and hence the term anterior choroid plexus is appropriate (*splx.*, Fig. 32). From the roof arises the pineal body (*epiph.*, Fig. 32), the remnant of a median eye. On the floor of this region is

located the prominent crossing of the optic nerves (II, Fig. 33) called the optic chiasma. Posterior to the optic chiasma is seen a tubular enlargement, the infundibular lobe, partly nervous and partly glandular (*inf.* and *hyph.*, Fig. 33). This small structure of the brain bears a most important relation to normal growth and certain

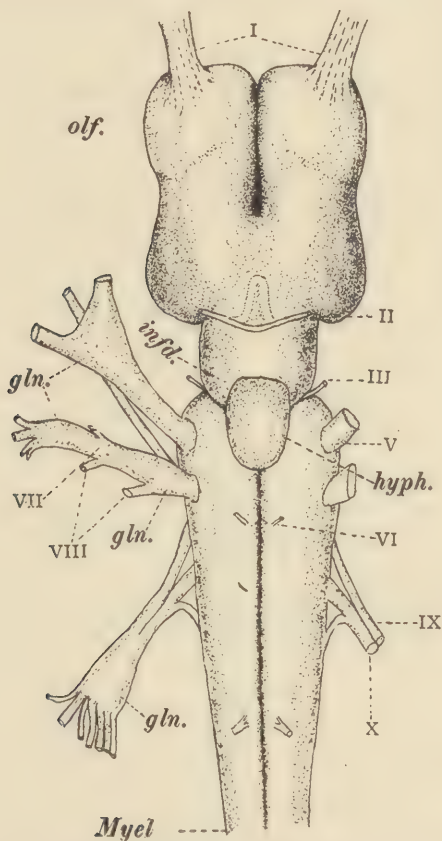


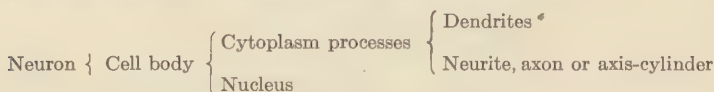
FIG. 33.—Brain of *Necturus maculatus*, ventral aspect. $\times 5.4$. *gln.*, ganglion; *hyph.*, hypophysis; *inf.*, infundibulum; *Myel*, spinal cord; *olf.*, olfactory portion of cerebral hemisphere; I to X, cranial nerves. (Kingsbury.)

diseases. The cerebral hemispheres are elongated bodies, tapering anteriorly. Near the anterior end a slight constriction marks the division between the cerebral and olfactory regions. It should be noticed that the olfactory lobes lie anterior and not beneath the cerebral lobes, as in higher vertebrates. The cerebral lobes are

entirely isolated from the sense organ and the organs of the body. No nerves enter or leave them. Therefore all nerve impulses must first pass through some other region of the brain and all commands issuing from the cerebrum must pass through a second region of the brain before reaching their destination. There is no way of measuring the influence that these associated regions of the brain may have upon the nerve impulses that start from the cerebral hemispheres. This important fact is equally as true for man as for the frog. The distribution of the several cranial and spinal nerves and the sympathetic system should be determined in the laboratory. (Compare Figs. 30 to 32.)

Tissues of the Central Nervous System.—The nervous system is composed of three distinct tissues, two of which play a minor, although essential, part in the work of the whole system. These minor tissues are the connective and the blood tissue; the former supply the protective sheaths and supporting framework, while the latter carry food to all parts and remove the wastes of metabolism. While these two tissues are everywhere present, yet they occupy but a relatively small part of the nervous system. The third tissue is the nervous, which represents the most highly specialized cells found in any tissue. Pure nerve tissue such as exists for epithelium is not found in the frog, for the nerve cells rarely join and always have in the frog protective and connective cells that bind them together. Again, a pure nerve tissue would be of no service to the frog unless the nerves were connected with the skin, muscles, etc.

Neuron.—In order to understand the histology of any region of the central nervous system the nerve cell must be studied.



This diagram and Fig. 34 will help to make clear the several parts in this cell which has become so highly specialized. The term neuron is given to the entire nerve cell, which is to be regarded as a unit of structure. The cell body is much like other cells, varying in shape and size, but has in addition outgrowths from the cytoplasm which are given the general name of processes and are divided into two kinds, dendrite and neurite. It is the processes that indicate the extent of specialization that has taken place in nervous tissue as compared, for example, with epithelial tissue. The large cells in the ventral region of the gray substance of the spinal cord as seen in the labora-

tory have several short processes that are branches; these are the dendritic processes (Fig. 34). Each of these cells is somewhat conical, and from the point a slender non-branching process arises which can be traced but a short distance; this is the neurite or axon. By the use of special nerve stains the axon of these cells can be traced out

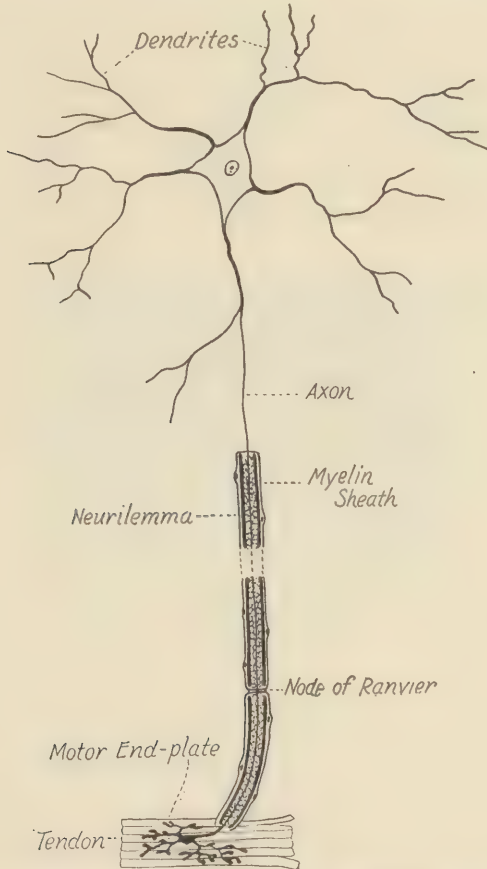


FIG. 34.—Motor neuron or effector nerve cell of *Rana pipiens*. Drawn from author's preparations.

into the nerve roots that arise from the ventral region of the cord. This axon continues in the nerve to end finally in some muscle. Thus the axons that pass to the hind feet might be six inches long in a large frog, which would make the total bulk of the axon many times that of the cell body which produced it.

The neuron just described is one of the most highly specialized cells found in the body of the frog. Some of the neurons are simple epithelial cells specialized to receive some form of physical or chemical

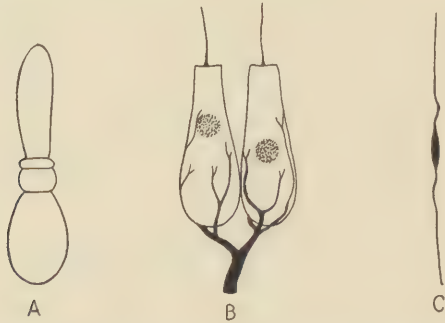


FIG. 35.—Three types of sensory neurons or receptor nerve cells. *A*, retinal rod from the retina of *necturus* and stimulated by light waves; *B*, modified ciliated epithelial cells from the lateral line sense organs of *squalus acanthias*. These cells are stimulated by low vibrations similar to sound waves. Redrawn from Johnston; *C*, neuro-epithelial cell from the nasal cavity of an embryo turtle. This cell sends its own axon to the brain.

stimulus. The neurons shown in Fig. 35 are readily recognized as simple cells, yet each is specialized to receive a given stimulus only.

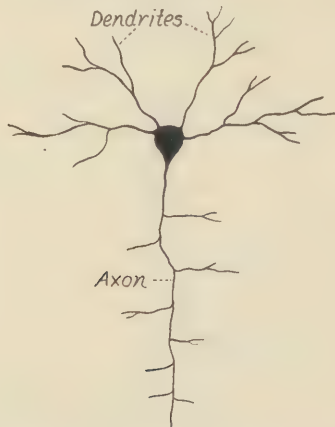


FIG. 36.—Association nerve cell. This class of nerve cells lies wholly within the central nervous system. From the cerebrum of the rabbit.

Within the brain and spinal cord is found a third type of neuron that simply conducts stimuli from one region to another. These are the association neurons, and they are very numerous. The thousands of

neurons in the nervous system of the frog are arranged into three classes: (1) The sense organs or receptors; (2) associational neurons; (3) those that carry stimuli directly to the muscles, to which the term effectors is given.

Origin of Processes.—The nerve cells arise in the embryo as rather regular columnar epithelial cells, with an entire absence of processes. As the embryo frog develops small outgrowths arise on the cells that are to become processes. These continue to grow, deriving their growing energy from the cell body. As they first arise they are naked processes, many of which remain as such throughout the life of the frog; but part of them become surrounded by well-defined, thick, fatty sheaths, the medullary sheaths, which are secreted by the processes which are thus enveloped (Fig. 37).

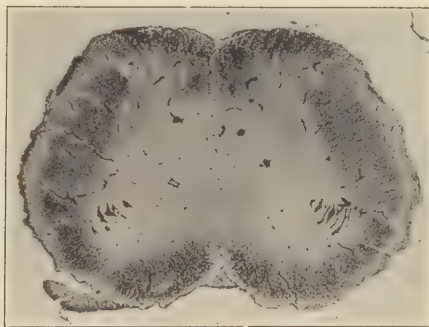


FIG. 37.—Photomicrograph of spinal cord of *Rana pipiens*. The motor nerve cells are stained black.

Histology of the Spinal Cord.—An analysis of the finer structure of the spinal cord will serve to illustrate the complexity of this highly specialized organ and give some insight into the way it works. The whole spinal cord is enclosed in a strongly protective membrane, the pia mater. Within the pia mater the cord is constricted on the dorsal and ventral surfaces. These constrictions are the dorsal and ventral sulci (posterior and anterior fissures of human anatomy). The area of the cord when seen cut in cross-section is made up of a peripheral layer of white substance in a fresh section, the white appearance being due to the fat in the medullary sheaths of the axons in this region and of the central area of gray substance. In the regions where the spinal nerves arise the gray substance extends in strands to the surface of the cord. This gives to the gray substance much the shape of an expanded butterfly. The white substance of

the cord is occupied mostly by medullated nerves running longitudinally, while the gray substance is composed of numerous nerve cells and their unsheathed processes. The center of the gray substance is occupied by a small cavity, the neurocele, which is surrounded by epithelial cells, the bases of which can be traced far out into the substance of the cord. This central nervous cavity extends throughout the length of the central nervous system and becomes expanded in the brain into the four ventricles (Fig. 31). At certain definite places the nerve fibers in the cord cross (Fig. 38). Here and there in any section of the spinal cord bits of capillaries show with their contained blood corpuscles.

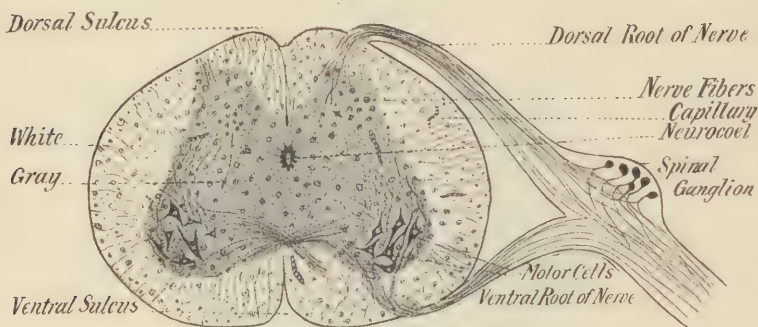


FIG. 38.—Diagram of spinal cord of frog.

Nerves.—Between the segments of the spinal column, pairs of spinal nerves pass off from the cord. Each nerve arises by two roots from the cord: one from the dorsal region and one from the ventral. On the dorsal root there is a small enlargement that contains many cell bodies which give origin to nerve processes. The presence of these nerve cells on the dorsal root distinguishes the two roots as to form as well as to function. The ventral root is mostly made up of fibers which grow out from the large cells in the ventral region of the gray substance and the most of them end in some muscle. This means that the nerve stimulus travels outward and away from the spinal cord over these fibers. This also means that these fibers cannot be stimulated normally except through the spinal cord. The term motor or efferent is given to the ventral root. The dorsal root consists exclusively of fibers which arise from the cells in the dorsal ganglion. Part of these fibers pass out into a nerve and are enclosed in the same general sheath with those from the ventral

root for a part of the way. The dorsal root fibers end in the skin.¹ From the same dorsal ganglion cells fibers grow into the spinal cord and send branches in several well-known directions. The normal stimulus for the dorsal root fibers is something that reacts on the fiber ending in the skin. Such a nerve impulse is carried to the spinal cord, where it is interpreted usually through the assistance of the brain, and the resulting explanation is sent out over the motor fibers to the muscles. The dorsal root, then, is known as the sensory or afferent root. Such is the structural plan of each spinal nerve. The nerves that arise from the brain have lost some of their primitive parts and each must be studied separately. Within the central nervous system there are many definite paths over which certain nerve impulses travel, but their study belongs to a course in neurology.

Stimulation of Nerves.—The most conspicuous feature of the nervous system is its power of responding to light, heat, touch, sound, etc., that is, to a stimulus. This power of being aware of the various stimuli is based upon a fundamental characteristic of protoplasm known in biology by the name of irritability. Originally all of the cells possessed this property, but as they grew into bone, muscle, etc., there was no need for irritability and it remained undeveloped. But irritability is only part of the work of responding to a stimulus, the light or heat stimulus is conducted along the nerves to the central nervous system. Here it is interpreted and the frog acts according to the nature of the stimulus. For the frog to respond to a stimulus involves the use of three highly developed fundamental protoplasmic properties, *i. e.*, irritability, conductivity and coördination. These three processes, then, are at work in every nervous response of the frog.

Habit Formation in Frogs.—"July 29, I placed 30 of the hairy caterpillars in the cage. *Rana sylvatica* attempted to eat a caterpillar seven different times within an hour but rejected it each time. Following these trials no other caterpillars were visibly reacted to. By attempting to eat a caterpillar and then rejecting it is meant this: The frog shot out the tongue in the normal manner, bringing the caterpillar back to the mouth, then extruding the tongue slowly, slightly wriggling it. In most cases this muscular wriggling freed the caterpillar from the tongue; if it did not the withdrawal of the tongue into the mouth scraped off the caterpillar in nearly every case." On August 9, 12.30 P.M., "The caterpillar was placed in the

¹ No attempt is made in this elementary book to present the functional divisions of the dorsal and ventral roots.

cage again, *Rana sylvatica* reacted first by making two short hops to orient so as to look directly at the caterpillar. (The caterpillar was about 5 cm. in front of the frog.) The head of the frog was then slowly lowered and brought forward toward the caterpillar, but I could not see that the tongue was shot out, although I watched especially to see if this would happen. In a second or two the head lurched forward a little more and then the tongue was very slowly extended, barely touching the caterpillar. The tongue was now withdrawn and then suddenly extruded, with what appeared as a very slight attempt to shake the caterpillar off. The caterpillar elicited no further response during the next forty-five minutes." For four days the frogs were scantily fed and then a caterpillar was put in the cage. *Rana sylvatica* took no notice of it. *Rana sylvatica* formed the habit of avoiding hairy caterpillars in seven trials.¹

Organic Movement.—The power to make a definite kind of movement was characterized in the first chapter as an exclusive property of living things. The kind of movement meant was such as grows out of the complex series of interacting stimulations that follow. The frog may be assumed to see a man approaching, the sight stimulation is carried to the brain and there are sent out impulses to the muscles which result in a series of movements so directed that the frog is able to jump into the water and swim away from shore. In these simple reactions there is one fact of great importance when these changes are contrasted with inorganic movement, that is, that the frog can change the direction in which he is moving. It makes very little difference how this fundamental characteristic of living matter is named; it may be called movement, coördination or response to a stimulus (having the property of irritability). The fact remains that it is universal in all higher animals. In the study of paramecium, a single-celled animal, similar relations exist (Chapter VIII). The tendency for the higher plants to remain stationary has resulted in the elimination of this property (Chapter XIII). Movement in its simplest expression is regarded as regulated by the nervous system without the intervention of the brain. The stimulation comes from the skin and is reflected by the cord to the muscles, and so the term reflex action is employed to describe the simple forms of movement.

LORSAR, WM.: A Study of the Function of Different Parts of the Frog's Brain, Jour. Comp. Neurol., 1905, vol. xv.

WYMAN, A.: Anatomy of the Nervous System of *Rana Pipiens*, Smithsonian Contributions to Knowledge, 1853, vol. v.

¹ Schaeffer: Habit Formation in Frogs, Jour. Animal Behavior, 1911, No. 5,

CHAPTER VII.

EMBRYOLOGY.

Somatic and Germ Cells.—Until one has actually seen the single-celled ovum change into many cells, elongate, and become a tadpole and finally a frog, the statement that such is the sequence of events seems incredible. In selecting the frog to illustrate the principle

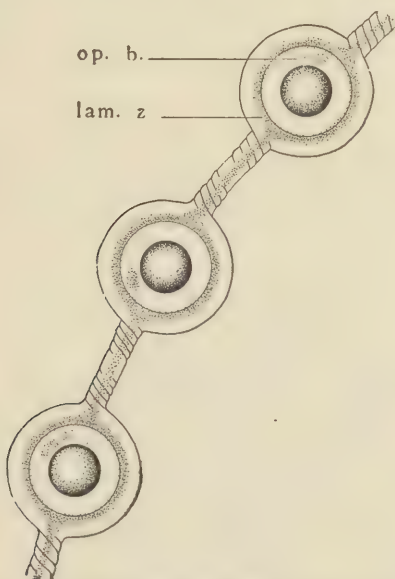


FIG. 39.—Eggs and egg envelopes of *Cryptobranchus*, natural size. *op. b.*, opaque body; *lam. z.*, lamellar zone of the envelope. (B. G. Smith, in *Journal of Morphology*.)

of growth and the origin of a new organism in Nature, for the two are continuous and inseparable processes, the purpose is to consider it in its broader aspects. The parent frogs possess either spermaries in which are produced sperms or ovaries that grow many ova. Both sperms and ova are free cells and do not unite to form tissues like epithelium or muscle. This free state is a primitive condition, and if these cells had some physiological work like digestion to perform,

they would be inefficient. But early in the life of the frog the cells which are to be responsible for growing sperms and ova are set apart and never develop into highly specialized adult tissue cells. This

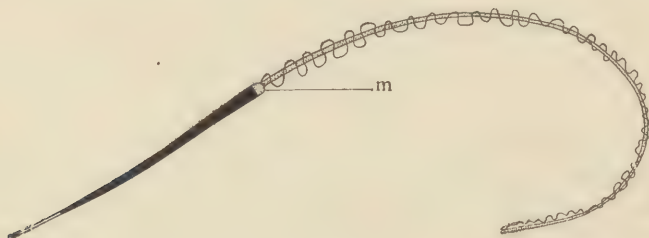


FIG. 40.—This highly specialized cell develops from one that has a nucleus, surrounded by cytoplasm. The conical, dark body is the sperm head and corresponds to the chromatin of the nucleus. The portion with the wavy margin is the tail and is all that remains of the cytoplasm. Spermatozoön. *m*, middle piece. $\times 500$. (B. G. Smith, in *Journal of Morphology*.)

gives in each frog one class of cells that continue to grow, eventually becoming highly differentiated. During this growth the cells are specialized and united into definite tissues, which in turn are distributed into complex organs. After such cells have become thus

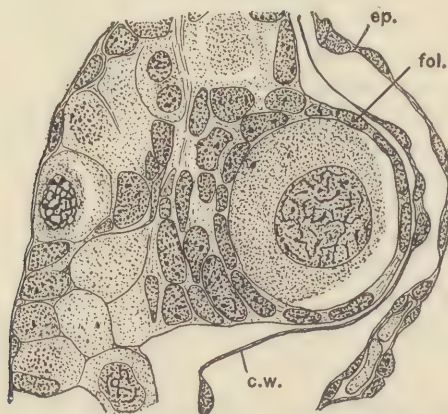


FIG. 41.—The largest cell is the young ovocyte of *Cryptobranchus*. In what particulars is it similar to the other cells in this figure? *ep.*, inner epithelial membrane of the ovarian wall; *fol.*, follicle cell; *c.w.*, cyst wall. (B. G. Smith, in *Journal of Morphology*.)

specialized they lose their power to grow new cells other than those like the tissue in which they occur. The term somatic cells is given to all such cells. The sperm and ovum cells are never in their adult

form united into tissues and they retain their power to grow new cells. They are called germ cells.

Ova and Sperm Cells.—The ovum of the frog is not a typical germ cell because the cytoplasm is packed full of stored-up food known as deutoplasm (Fig. 43). The result is that most of the cytoplasm and the nucleus are crowded into one region of the ovum. Associated with this concentration of cytoplasm is a black pigment. This pigmented region is called the animal pole of the ovum and

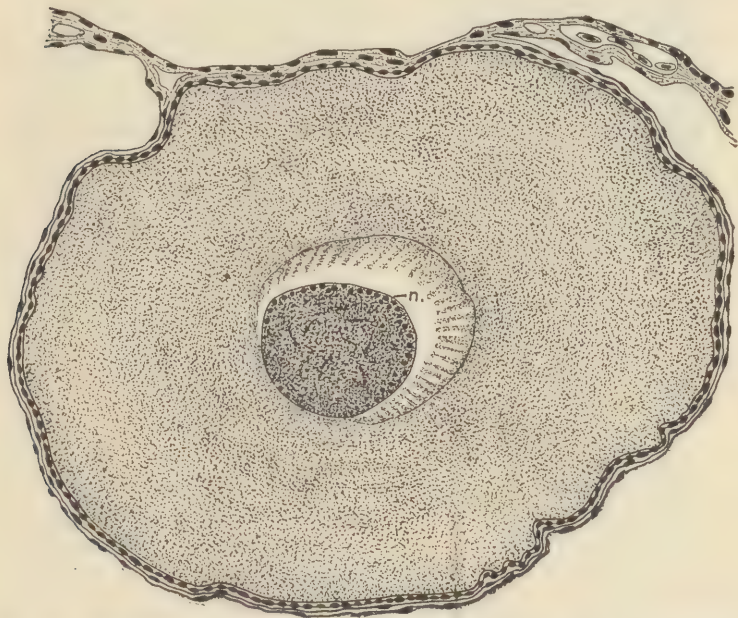


FIG. 42.—Section through an ovocyte and ovarian wall of a 35 cm. *Cryptobranchus*, showing the follicle and the distribution of nucleoli. Compare this stage with Fig. 41. (B. G. Smith, in *Journal of Morphology*.)

the opposite region the vegetal pole. The pigmented area is always uppermost and directed toward the sun because the animal pole is of less specific gravity than the vegetal region.

The highly specialized ovum of the frog represents a cell that started out with a central nucleus surrounded by cytoplasm. During the growth of the young ovum, which is usually termed an ovocyte, there is deposited in the cytoplasm the deutoplasm. Deutoplasm is made by the life processes of the ovocyte and is a product of

constructive metabolism. This means that the inert deutoplasm of the frog's ovum must have been living ovocyte protoplasm at one stage. Such stored-up energy is used by the developing embryo.



FIG. 43.—Portion of a section through one of the most advanced ovocytes of a 35 cm. *Cryptobranchus*, showing the structure of the membranes surrounding the egg and the early formation and distribution of yolk granules (deutoplasm). $\times 340$. c., cyst membrane; cy., yolk-free peripheral zone of cytoplasm; ep., inner epithelial membrane of the ovarian wall; fol., follicular membrane proper; z.p., zona pellucida; z.r., zona radiata; y. and y', layers of fine and coarse granules respectively. (B. G. Smith, in *Journal of Morphology*.)

After a study of the ovocyte stages in Figs. 41–44 and the ovum as shown in Fig. 44, explain how the ovocyte is changed from one stage to another. Does the term growth correctly describe these changes? Define growth in terms of the ovocyte and ovum.

The sperm cell has departed from the rounded primitive shape for cells and has assumed a highly specialized form. The cytoplasm has become reduced to a very small amount and forms the tail, while the nucleus is concentrated into a solid mass of chromatin, the sperm head. The long vibratile tail assists in the movement necessary to bring the sperm cell to the ovum (Fig. 40).

When the eggs are first extruded they are surrounded by a thin mass of gelatinous substance secreted by the cells in the wall of the oviduct. This may be briefly referred to as jelly. Within one minute after the egg is laid the jelly begins to absorb water. In from ten to fifteen minutes it becomes about six times as thick as when first brought in contact with the water. As this thickening takes

place, definite layers can be made out in it. The jelly serves to unite the eggs in a mass to protect them from mechanical injury and to prevent them from being eaten by microscopic animals. The ova are numerous spherical bodies about 1.75 mm. in diameter.

Black in color, they readily absorb heat. The sperms and ova may be frozen without being destroyed if the exposure is short.

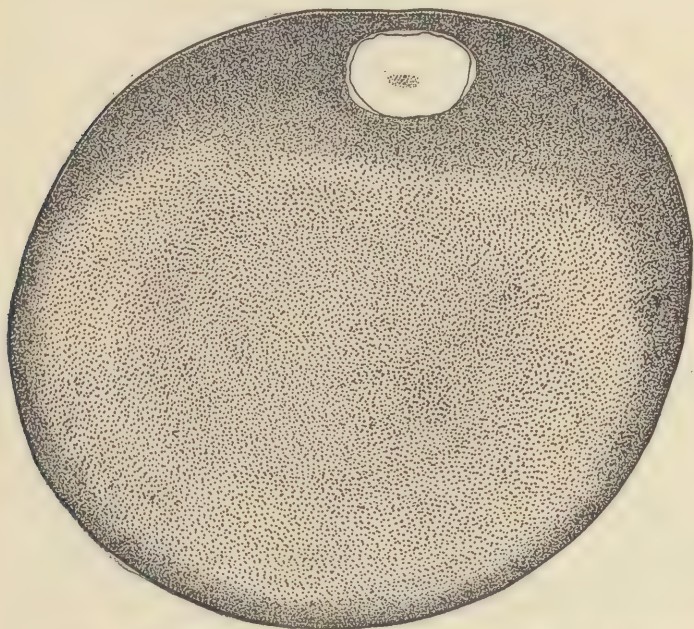


FIG. 44.—Ovarian egg of adult *Cryptobranchus*. How does this egg differ from the ovocyte? (B. G. Smith, in *Journal of Morphology*.)

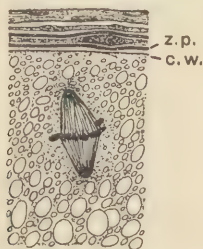


FIG. 45.—Showing first polar spindle of *Cryptobranchus*. c.w., cell wall formed from the zona radiata; z.p., zona pellucida. There are probably six large chromosomes forming a ring surrounding six small chromosomes in a state of division. The chromosomes are the black bodies. (B. G. Smith, in *Journal of Morphology*.)

Rana catesbiana breeds from June 15 to August 1. The large egg-mass is laid in a short time. The egg-mass has a pancake-like

shape from one to three feet across, and in it are found from 12,000 to 20,000 eggs which hatch in from three to five days.

Maturation.—The term maturation is used to describe several important changes that take place in the full-sized egg before fertilization is possible. These changes are mainly limited to the nucleus. The nucleus of the ovum contains too much chromatin and the excess must be removed and forced through the cell wall (vitelline membrane). The process of getting rid of the chromatin consists of a series of detailed changes that are well illustrated in Fig. 46, *B*. In this process there are two general features that may be emphasized: (1) The changes in the chromatin; (2) the method by which the chromatin is removed. The conditions diagrammed in Figs.

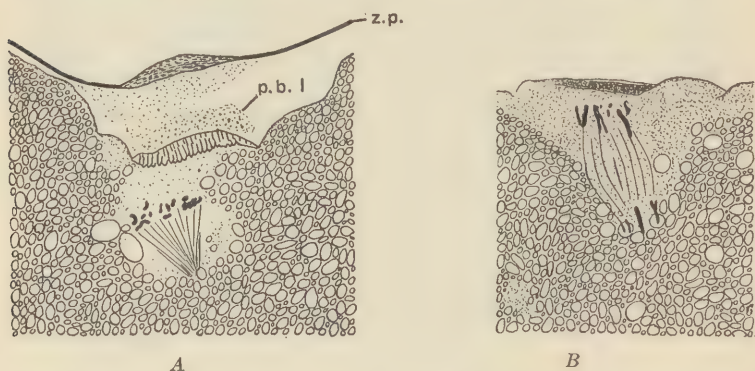


FIG. 46.—Sections showing the second polar spindle, and the formation of the second polar body of the egg nucleus in *Cryptobranchus*. z.p., zona pellucida; p.b. 1, debris of the degenerating first polar body; B, late anaphase, second polar spindle. (B. G. Smith, in *Journal of Morphology*.)

48–51 illustrate the usual method by means of which the cell divides. It is called the mitotic or indirect method of cell division.

The mechanism for the removal of the excess of chromatin consists in the formation of a temporary structure in the cytoplasm, the spindle. The exact origin of all of its parts is still a subject of controversy, and they are not the same in all animals. The conditions in the frog are about the same as shown in the illustration for *Cryptobranchus*. A spindle arises in the cytoplasm close to the egg nucleus; it is made up of fibers which extend from pole to pole of the spindle as well as fibers which radiate around each pole; these latter are known as the astral fibers (Figs. 48 and 49). The astral fibers terminate in a deeply staining body known as the centrosome.



FIG. 47.—Vertical sections of egg of *Cryptobranchus*, showing penetration of the egg by a spermatozoön. $\times 240$. Two and one-half hours after fertilization. (B. G. Smith, in *Journal of Morphology*.)

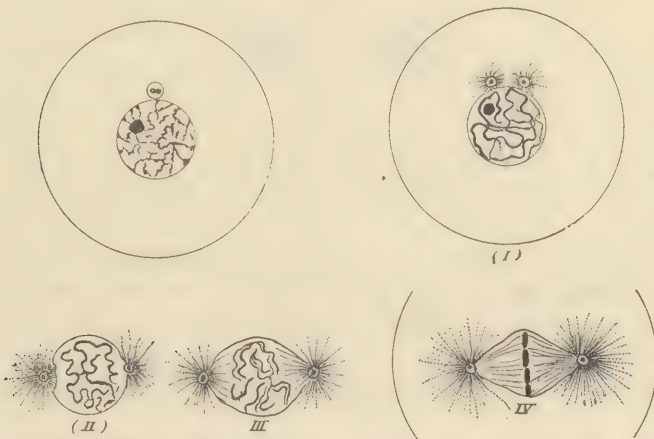


FIG. 48.—Prophases of karyokinesis. *I*, division and migration of centrosome; *II*, resolution of chromatin into well-defined thread; *III*, segmentation of same into chromosomes; *IV*, development of amphitasters; chromosomes equatorial. (Wilson.)

As the spindle grows some of the fibers push their way through the weakening nuclear membrane and come in contact with certain chromatic masses that have become larger during the time that the spindle was forming in the cytoplasm (Fig. 48, *IV*). These particular chromatin masses continue to enlarge and become organized

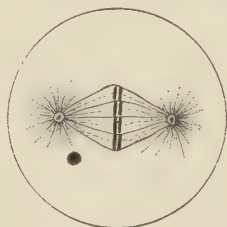


FIG. 49.—Metaphase of karyokinesis. (Wilson.)

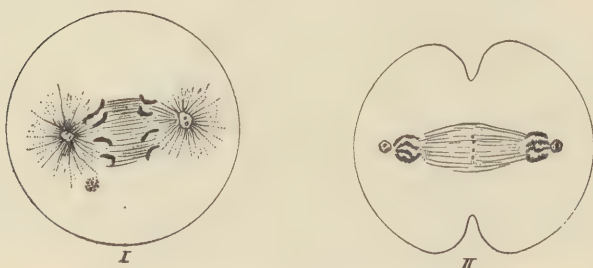


FIG. 50.—Anaphases of karyokinesis. (Wilson.)

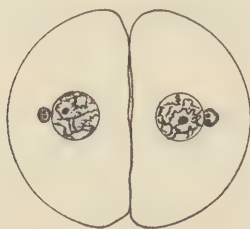


FIG. 51.—Telophase of karyokinesis. (Wilson.)

into a definite number of discrete chromatin bodies which are now termed chromosomes. The number in the common toad is 12, in *Rana temporaria* 10 and in *Cryptobranchus* 12, and they are constant for each species.

The chromosomes are drawn into the spindle until they are arranged

symmetrically midway between the two poles of the spindle. The growth of the spindle and the increase in size and arrangement of the chromosomes between the poles of the spindle is a preparatory process and is named the prophase stage. The number of chromosomes and the amount of chromatin is the same in each species.

As soon as the chromosomes take the equatorial position and divide (Fig. 49) it is customary to use the term metaphase in describing this second stage. In a short time the chromosomes divide, each chromosome splitting into two equivalent parts, which move toward each pole of the spindle (Figs. 46, *B* and 49). One pole of the spindle moves to the periphery of the ovum, and by the constriction of a small portion of the cytoplasm this distal pole of the spindle and the chromosomes associated with it are cut off from the rest of the ovum (Fig. 46, *A*, *p.b.* 1). The obvious result is that



FIG. 52.—Section through an egg killed ten and one-half hours after fertilization, showing the sperm nucleus. Compare this nucleus with the sperm head in Fig. 40. (B. G. Smith, in *Journal of Morphology*.)

one-half of the original amount of the chromatin in the nucleus has been removed from the ovum. The parts thus removed by this process constitute the first polar cell. The portion of the spindle remaining in the cytoplasm, except the centrosome, dissolves and is transformed into the cytoplasm. A new spindle arises now under the direction of the old centrosome that remained in the ovum. The work of the new spindle repeats the process already described and there is produced a second polar cell. At the close of the formation of the second polar cell the remaining chromosomes gradually become transformed into a nucleus, but a nucleus that has lost three-fourths of its original amount of chromatin. This process is termed maturation and is preparatory to fertilization. The new nucleus is called the *female pronucleus*, to distinguish it from the nucleus of the ovum (Fig. 53). The two polar cells soon disintegrate and play no

further part in development. The first polar cell is formed and the second polar division has reached the metaphase stage by the time the egg enters the lower end of the oviduct. The remaining steps in the formation of the second polar cell usually do not take place until after the eggs have been laid and the sperm has entered into the cytoplasm (Fig. 47).

Fertilization.—While maturation is thus taking place the sperm enters the ovum (Fig. 47) and is gradually transformed into a nucleus (Fig. 52). This change results through the increase in size of the sperm head, which is nearly all chromatin; it gradually becomes vacuolated and secretes its own nuclear membrane. In appearance this sperm nucleus is like the egg nucleus, while in many instances it is as large; in *Cryptobranchus* it is much smaller (Fig. 53). As a rule one must know the exact history of the two nuclei found in

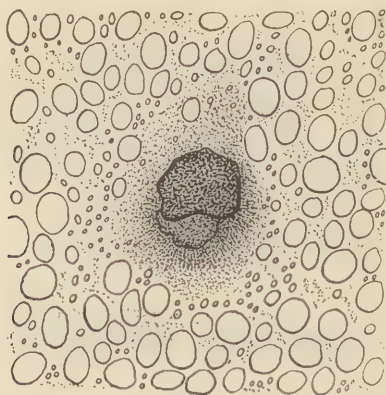


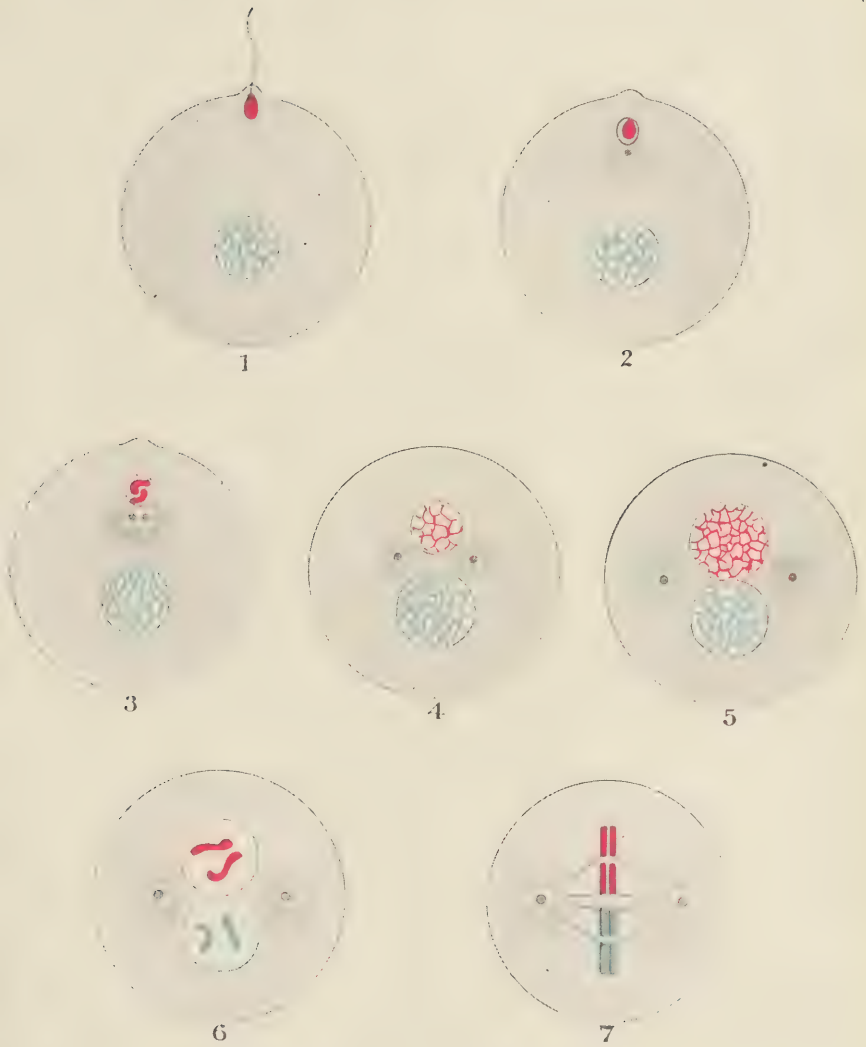
FIG. 53.—Section through egg killed twelve hours after fertilization, showing the fusion of the male and female pronuclei. The male pronucleus is probably the smaller. (B. G. Smith, in *Journal of Morphology*.)

an ovum during fertilization in order to be able to tell their origin, so similar are the two. The male nucleus in the ovum is called the *male pronucleus*.

As the two pronuclei grow to full size the male pronucleus moves through the cytoplasm until it comes in contact with the female pronucleus (Fig. 53). At about this time the nuclear membrane of each begins to break down and the contents of the two pronuclei¹ become enclosed in a single, irregular-shaped nucleus. *This uniting of the two pronuclei is fertilization.* Fertilization takes place outside

¹ For the discussion of the significance of male and female chromosomes, see chapter on Heredity.

PLATE I



Fertilization. (After Adami.)

1. Entry of spermatozoön into ovum. 2. Loss of tail of spermatozoön. 3. Division of centrosome. 4 and 5. Chromatin both of ovum and spermatozoön converted into a network; the two moieties gain approximately equal size. 6. Chromatin of both becomes arranged into chromosomes (one-half of the number of each variety that is usual in the body cells of the species). 7. Formation of spindle; division of chromosomes; partition of chromosomes derived from the two parents in equal number between the two future cells (blastomeres).

of the body of the frog. It is difficult to state to just what extent the chromosomes of each pronucleus retain their identity and to what extent they fuse. At any rate the number of chromosomes is not increased by fertilization. This new nucleus resulting from the fusion of the male and female pronuclei is termed the *segmentation nucleus* and the ovum is now properly designated as an embryo.

Segmentation.—After maturation and fertilization the egg begins to show signs of segmentation. The time varies with the temperature, being usually two or three hours after fertilization. Segmentation begins as a vertical furrow in the pigmented region (Fig. 54). This furrow continues until it surrounds the embryo. A division of the nucleus precedes this cytoplasmic segmentation. The result of this constriction is to cut the embryo into two cells. Where the segmentation divisions pass entirely through the embryo it is said to be

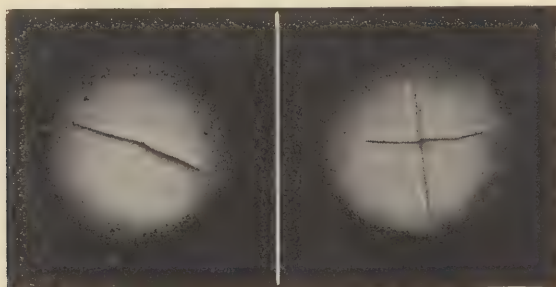


FIG. 54.—Photographs of the first and second cleavage in *Cryptobranchus*, animal pole. (B. G. Smith.)

total. The second segmentation begins about one hour after the first and in a similar manner, but in a vertical plane at right angles to the first (Fig. 54). The third segmentation in the frog is not just like that shown for *Cryptobranchus* (Fig. 55), but is in a horizontal plane at right angles to the first two and a little above the equator of the embryo, which results in producing eight cells, four small ones at the animal pole and four large ones at the vegetal pole. The third division of the embryo results in forming four small cells and four large cells. This cleavage is thus unequal. The first division of the frog embryo illustrates what is meant by total *segmentation* or *cleavage* in the embryonic development of an animal, while the third division is described as unequal segmentation. Segmentation takes place from now on more rapidly at the animal pole and in a short time the cells at the vegetal pole are found to be much larger than those at the

animal pole (Fig. 56). The rate of division is intimately associated with the quantity of yolk present. There are a number of external changes which can be readily observed.

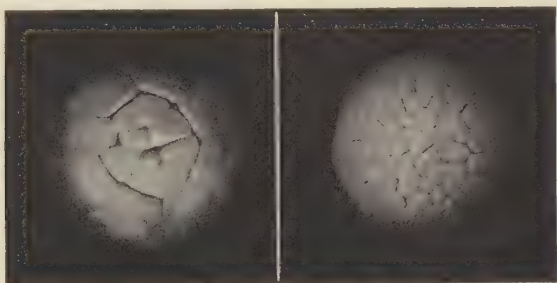


FIG. 55.—Photographs of later cleavage stages in *Cryptobranchus*, animal pole. (B. G. Smith.)

As the cells at the animal pole continue to grow more rapidly than those at the vegetal pole they soon spread over these large cells. This results in forming a layer of small cells which almost completely surrounds the embryo. The term *germ layer* is given to such a layer of cells. As the development continues two more germ layers can

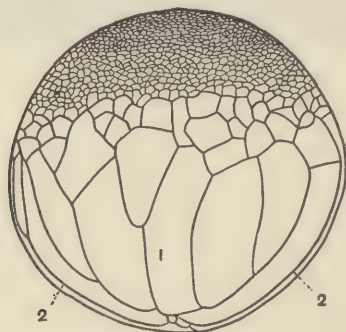


FIG. 56.—Stage nine of the cleavage of *Cryptobranchus*. Equatorial. Note the difference in size of cells at the two poles. (B. G. Smith, in *Journal of Morphology*.)

be recognized. The one on the outer surface is the ectoderm. The primitive digestive canal is lined with the germ layer known as endoderm; while the third layer is the mesoderm. From each of these germ layers the organs of the frog are derived.

The ectoderm gives rise to the skin, nervous system, parts of all of the sense organs, as eyes, ears, etc. The mesoderm forms the muscles, skeleton, blood and bloodvessels, kidneys and reproductive organs. The liver, pancreas and mucosa of the intestinal tract come from the endoderm.

For a considerable time the embryo retains its spherical form (Fig. 56). One of the first changes to be noted is a flattening on the dorsal surface (Fig. 57). A groove soon appears in this region which is the neural groove. The edges of the neural groove unite, enclosing a cavity. This union begins at the anterior end, thus

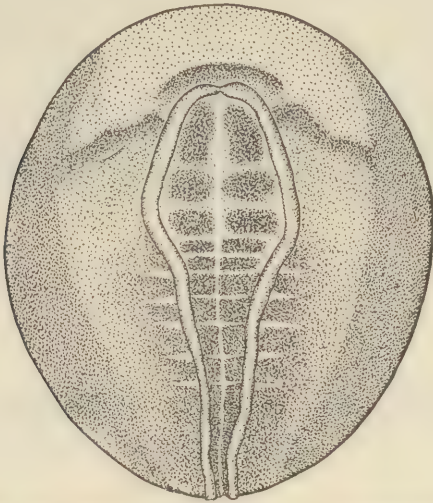


FIG. 57.—Anterodorsal view of a living embryo of *Cryptobranchus*, viewed mainly by transmitted light, showing neural groove. Free-hand sketch. (B. G. Smith, in *Journal of Morphology*.)

forming first the forebrain and more posteriorly the spinal cord, both of which are derived from the ectoderm. During this time the embryo has elongated in a direction which marks the longitudinal axis of the animal. The mouth, anal opening, nostrils, gill-slits and sucker appear as the embryo elongates.

Tadpole.—It is from four to five days after hatching before the mouth becomes connected with the remainder of the digestive tube, and during this time the tadpole is dependent for food on the unused yolk (Figs. 58 and 59). The tadpole soon attaches itself by means of its sucker to weeds, etc., and breathes by means of three pairs of external gills. Soon after this stage the mouth becomes connected

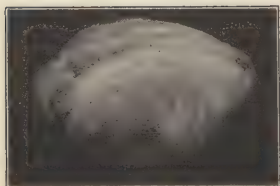


FIG. 58

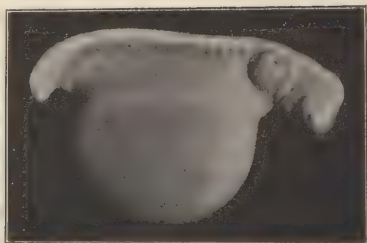


FIG. 59

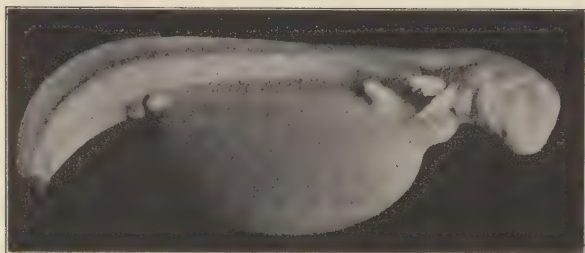


FIG. 60

FIGS. 58, 59 and 60.—Embryos of *Cryptobranchus*, showing the gradual formation of the body and the presence of the yolk. (B. G. Smith, in *Journal of Morphology*.)



FIG. 61

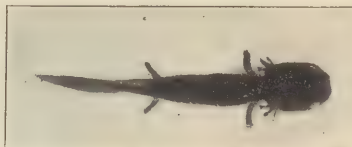


FIG. 62



FIG. 63

FIGS. 61, 62 and 63.—Fig. 61, larva of *Cryptobranchus* two months after hatching; Fig. 62, ten weeks after hatching; Fig. 63, larva one year old. The newly hatched larva retains a supply of yolk sufficient to last it from two to four months. Pulmonary respiration is established about five months after the hatching period. The metamorphosis takes place at the end of the second year. Sexual maturity is attained, probably at the end of the fourth year. (B. G. Smith, in *Journal of Morphology*.)

with the digestive tube, the intestine increases greatly in length and becomes much coiled and the tadpole feeds on minute animals. A few days after hatching a fold of skin grows from the side of the head to cover the external gills, leaving a small opening on each side the spiracle, which later closes on the right side, leaving a single spiracular opening on the left side for the exit of water. This fold of skin is the operculum. After the external gills are covered by the operculum they are gradually absorbed and respiration is accomplished by means of the internal gills, which appear about the time that the mouth opens. Up to this time the tadpole is a fish-like animal with a long vertically flattened tail. The muscle segments show on the side of the tail through the skin. *Rana catesbiana* lives for a year in this stage. During the second summer the hind limbs begin to appear as the tail is gradually absorbed, then the front limbs break through the skin and the tadpole becomes a frog. There are important and interesting internal rearrangements accompanying these external changes. The series of changes by which the tadpole is transformed into a frog is known as *metamorphosis*.

Life Cycle.—The study of the frog began with the adult animal composed of organs, tissues and thousands of cells. In the germ glands, eggs or sperms were produced that were set free during the breeding season. These united and an embryo resulted. The embryo underwent a series of segmentation stages which finally resulted in the production of a tadpole. After a time the tadpole transformed into an adult frog. The term life cycle is applied to all of the stages in the life of the frog beginning at any stage and continuing until this stage is reached again. The life cycle of the frog might begin with the adult and include the stages as given at the beginning of this paragraph; or it might begin with the tadpole or any other stage if all of the others are brought into their correct relation to the stage selected.

As the result of this study of the embryology of the frog, write a definition of growth employing the following terms: ovocyte, cleavage, nervous system and tadpole.

PART II.

THE FUNDAMENTAL PRINCIPLES OF BIOLOGY AS ILLUSTRATED BY UNICELLULAR ORGANISMS.

CHAPTER VIII.

PARAMECIUM—AN ANIMAL MADE UP OF A SINGLE CELL.

Habitat.—The animals whose bodies are composed of a single cell are to be found in definite environmental relations to other animals and plants. The mere fact that they are microscopic in size does not imply that the general conditions surrounding them are different from those of other organisms. The habitat of the frog was found to be in definite relation to water, to the seasons and to food.

Paramecium is found in both salt and fresh water and cannot live in any other medium. It is abundant in the temperate fresh-water ponds and streams, especially if the water is stagnant. It is easily kept in aquaria in the laboratory, if supplied with plenty of bacteria such as are present in a hay-infusion. Paramecium is not found in all fresh water. Ordinary drinking-water does not contain it nor is it found in abundance in flowing streams or large lakes. But in water that contains decaying plants and tends to be stagnant, paramecium is usually present. It is not necessarily present even in this ideal habitat, not being found in such conditions unless paramecia have been living there previously, for these microscopic animals follow the same manner of propagation as the frog; namely, there must be living paramecia to give rise to paramecia. When the food conditions are favorable these animals become very numerous, so that a student in a single laboratory period may have several hundred living paramecia for study. These animals are kept in the laboratory throughout the year, and year after year, so that it is evident that they are active throughout the entire year, although very little is known about their winter activities in nature as contrasted with the artificial conditions in the laboratory.

Appearance.—When a drop of water containing paramecia is placed on a microscopic slide they can be seen with the naked eye as grayish rods moving about rapidly. As soon as they are studied under magnification the body is discovered to have a constant shape which is more like a cigar than any other common object. There is a difference in the form of the two ends of the animal, and that end which usually goes foremost is called the front or anterior end. Paramecium can move either forward or backward, but it swims with the rounded, blunt end pointing in the direction that it is moving except when it becomes necessary to reverse its direction. While it is customary to use the terms anterior for the blunt end and posterior for the pointed end, these two terms do not indicate that there is a clearly defined head or anterior region as in the frog.

The body is broader toward the posterior end, so that the widest part is about two-thirds from the anterior end. In the usual outdoor culture of paramecia there will be found individuals varying in size from 300 micra to as small as 90 micra (a micron is $\frac{1}{1000}$ of a millimeter), which has been shown to be the natural range in size for these single cells of living protoplasm. In such a culture of paramecia it may be possible to distinguish between the larger animals that have the anterior half of the body rather slender and the posterior end markedly pointed, and the smaller forms which are slightly broader in proportion to length and taper less rapidly. When certain additional facts are added to those of size and shape, one can say that two species of paramecia are present.

Structure.—The body of the paramecium is covered with cilia which are slightly longer at the posterior end. On one surface there is a broad groove extending from the anterior end backward obliquely, ending about the middle of the body. As the groove extends posteriorly it deepens. At this place the mouth is located, which opens into a short gullet. For convenience in description the surface upon which this groove occurs is referred to as the oral or ventral surface.

The internal structure may be compared to any typical cell with cytoplasm and nucleus. The cytoplasm of the paramecium is easily recognized as consisting of an outer firm layer with very few coarse granules, known as the ectoplasm; and the inner, coarsely granular layer, the endoplasm. The thin layer of ectoplasm contains numerous rod-like structures, the trichocysts (Fig. 64). The ectoplasm is separated from the surrounding water by a thin cell wall (pellicle). Both the ectoplasm and cell wall are penetrated by the gullet and the anal opening which is located in the posterior part of the body. The

living cilia are in connection with the living cytoplasm beneath the cell wall.

Between the ectoplasm and endoplasm are located the two contractile vacuoles, one in the anterior and one in the posterior region. These structures undergo a series of rhythmic changes. There are a number of canals that connect the surrounding region with each

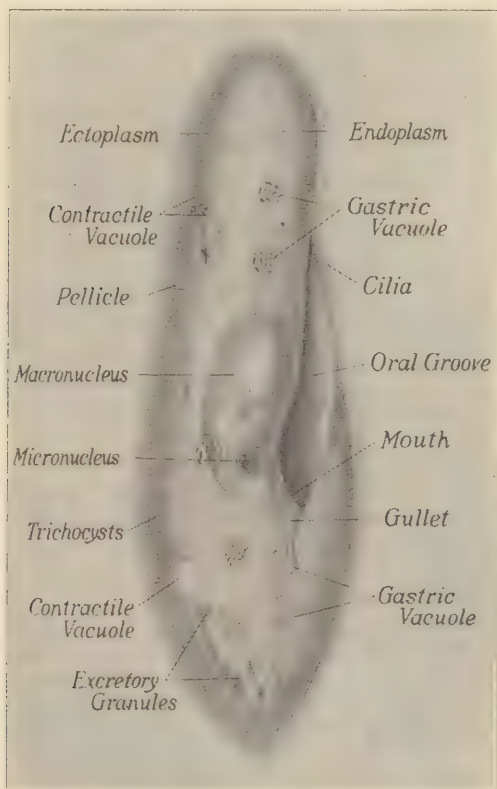


FIG. 64.—*Paramecium caudatum* drawn from living animal by Geo. T. Hargitt.

vacuole, and as the waste fluid flows through them into the vacuole it gradually becomes distended into a conspicuous vacuole in the part of the body where it is located. As soon as it is filled a contraction takes place in it and the fluid contents are discharged from the body. The two contractile vacuoles alternate in their action. When one is filling the other is emptying.

Within the thin peripheral layer of ectoplasm is the coarsely granular endoplasm containing a single large, roundish nucleus and one or

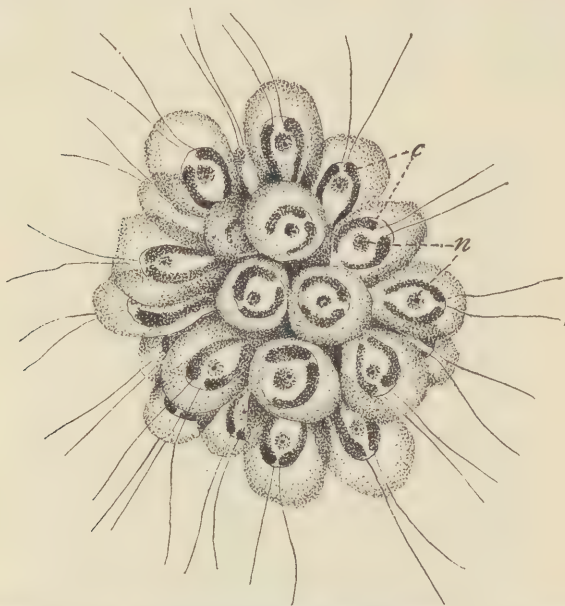


FIG. 65.—*Synura urella*, a colony of phytoflagellates, often a source of disagreeable odors and tastes in drinking-waters. (After Calkins.)

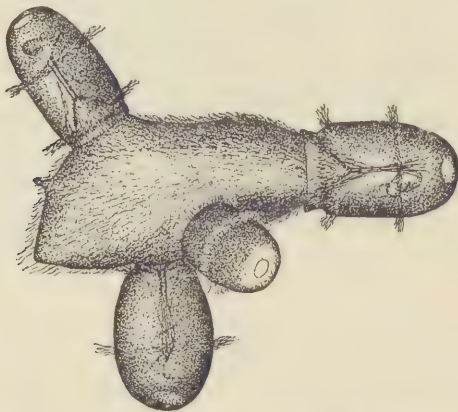


FIG. 66.—A large *paramecium* attacked by four small *didinium*. Under such conditions the *paramecium* is usually torn in pieces and each *didinium* gets a portion. Sometimes, however, one *didinium* gets the entire *paramecium*, forcing the others off during the process of swallowing. (Mast, Biological Bulletin, February, 1909, No. 3, vol. xvi.)

two micronuclei which are very minute and usually partly concealed, as they lie in a slight hollow in the surface of the macronucleus. The nuclei are located beside the oral groove, near the mouth. There are a varying number of vacuoles scattered in the endoplasm partly filled with food particles surrounded by water. The general term, food vacuoles, may be applied to all such vacuoles. As the animal is studied under the high power of the microscope it is easy to note that the endoplasm is a fluid through which the food vacuoles may move. The nuclei and contractile vacuoles retain their position in the cell but the coarse granules and food vacuoles move about with the streaming movement of the endoplasm. This movement of the endoplasm is independent of the general locomotion of the animal as it swims through the water.



FIG. 67.—A large *paramecium* immediately after having been attacked by a small *didinium*. The discharge of the trichocyst has mechanically forced the *didinium* back, drawing the seizing organ out and producing a marked protuberance on the surface of the *paramecium*. (Mast, Biological Bulletin, February, 1909, No. 3, vol. xvi.)

The single-celled *paramecium* is thus seen to have more parts than are to be found in the germ cells of a frog or in epithelial cells (Fig. 41). This suggests that these single-celled animals are not all of the same rank, but that some of them have undergone a differentiation and specialization. The *paramecium* does not represent as simple a form of organization as the *ameba* and a considerable number of other single-celled animals.

Physiology.—The frog carries on a series of vital activities which are easily compared. The frog utilizes organs and organ systems to do this. The following outline of the vital activities of the para-

mecium shows that there may be carried on within the protoplasm of a single cell all of the vital processes of the frog.

Locomotion.—No one who has ever observed living paramecia under the low power of the microscope can have any doubt concerning their power to move. While at first their darting movements appear to have no regularity, closer observation reveals that there is a great deal of regularity between what appear at first to be orderless dashings back and forth.

Jennings has given in the following the clearest description found of the general swimming of the paramecium in an unobstructed field: "The paramecium swims by the beating of its cilia. These are usually inclined backward, and their stroke then drives the animal forward. They may at times be directed forward; their stroke then drives the animal backward. The direction of their effective stroke may indeed be varied in many ways. . . . The stroke of the cilia is always somewhat oblique, so that in addition to its forward or backward movement, the paramecium rotates on its long axis. This rotation is over to the left (Fig. 68), both when the animal is swimming forward and when it is swimming backward. The revolution on the long axis is not due to the oblique position of the oral groove, as might be supposed, for if the animal is cut in two, the posterior half, which has no oral groove, continues to revolve.

"The cilia in the oral groove beat more effectively than elsewhere. The result is to turn the anterior end continually away from the oral side, just as happens in a boat that is rowed on one side more strongly than on the other. As a result the animal would swim in circles, turning continually toward



FIG. 68.—Spiral path of a paramecium. The figures 1, 2, 3, 4, etc., show the successive position occupied. The dotted areas with small arrows show the current of water drawn from in front. (From Jennings.)

the aboral side, but for the fact that it rotates on its long axis. Through the rotation the forward movement and the swerving to one side are combined to produce a spiral course (Fig. 68)."

The movement of the paramecium in an unobstructed field is thus seen to be a regular spiral, which may be said to be as characteristic as is hopping for the frog. But when the paramecium meets an obstacle, another paramecium or food its movements are equally characteristic, and a specific description can be given in each instance. In a more intensive study of the paramecium these various forms of activity are readily distinguished. Compare these movements with those in ameba.

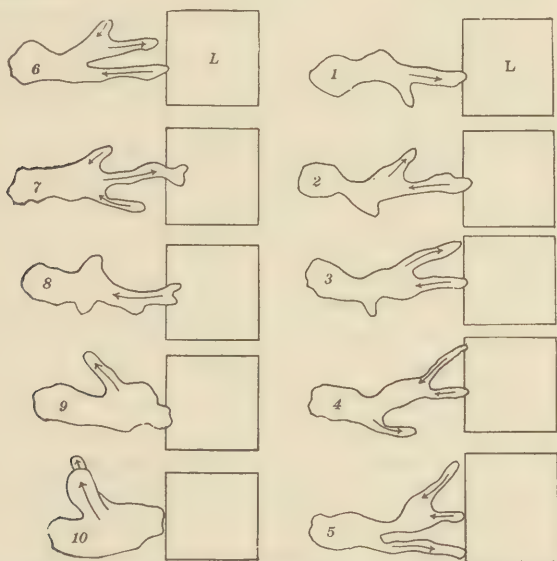


FIG. 69.—Sketches representing the reactions of an ameba proceeding toward an intense area of light, the rays of which were perpendicular to the slide. *L*, field of light formed by focussing a limited section of a Welsbach mantle on the slide. 1 to 10, successive positions of an ameba a little less than one-half minute apart. Arrows indicate direction of streaming pseudopods. Compare this method of locomotion with paramecium. (From Mast, *Jour. Exper. Zööl.*)

Movement in Ameba.—When an ameba is moving about and enters a brightly illuminated area, in nearly all instances it stops. "The details in the response which resulted in the change in direction of motion and thus kept the organism out of the intense light were essentially the same in all of the specimens observed. They are graphically recorded for a single individual in Fig. 69. By referring to this figure it will be seen that after one pseudopod came in contact

with the illumination and was stopped, the ameba did not at once proceed in the opposite direction so as to avoid the light, but sent out other pseudopods at only a slight angle with the first, apparently trying to get around the obstacle in this way. The character of the response did not change after the first pseudopod came in contact with the light, nor did it change after the second and third came in contact with it. But after the fourth became exposed the direction of motion was nearly reversed. This indicates that the reaction was modified, that the response to a given stimulus depends upon preceding experience." (Mast.)

Food.—Large quantities of bacteria are present in water in which paramecia are abundant, since these minute plants are their chief food. The activities of the paramecium in feeding consist in placing the body against a mass of bacteria and stopping the action of the cilia on the body, while those on the oral groove produce a strong current of water directed toward the mouth. The bacteria are thus carried to the mouth and swallowed. As the masses of bacteria pass into the endoplasm a small amount of water is also taken in. The result is the production of a distinct structure, surrounded by endoplasm called the food or gastric vacuole.

The number of food vacuoles depends upon the abundance of bacteria available. As the vacuoles accumulate in the endoplasm they can be seen to pass posteriorly and then gradually move toward the anterior end, finally, after several hours, being extruded from the body through the anal opening.

Digestion.—The gastric vacuoles in the endoplasm of the paramecium may be compared to the stomach of the frog. Neither the insects which are in the stomach of the frog nor the bacteria in the gastric vacuoles of the paramecium can be built up into living protoplasm until they have been digested. There are no digestive glands or special structures, so far as one can observe, whose main function it is to transform these bacteria, which are composed of proteins, carbohydrates and possibly fats, into diffusible products. It has been demonstrated that there is a mineral acid in the gastric vacuoles which kills the bacteria, after which the bacteria are seen to swell and then pass into solution. This is probably similar to protein digestion in the higher animals. Inasmuch as there are definite digestive ferments or enzymes that transform the food in all of the higher animals, it is assumed that one or more digestive enzymes are produced by the protoplasm of the paramecium because proteins, carbohydrates and fats are absorbed from the gastric vacuoles. The

paramecium is thus able to digest and assimilate food in a manner similar to the many-celled animals.

Excretion.—It is believed that the contractile vacuoles collect and discharge waste products to the outside of the body of the paramecium. There are also some specific granules which are regarded as excretory although their exact function is undetermined.

Respiration.—In addition to taking in food and giving off waste, the paramecium must have oxygen. This it is able to take from the water. There is no definite part of the body of the paramecium concerned in taking oxygen that is comparable with the lungs of the frog. As the excretory waste flows into the contractile vacuoles and then is in turn discharged from the body a certain amount of movement is produced in the endoplasm which probably helps in circulation.

Metabolism.—The manner in which the paramecium uses food, the evidence in favor of excretion and the utilization of oxygen warrant the use of the term metabolism in the same sense that it was used in describing similar activities in the frog.

Reproduction.—That this elementary vital process is present in the paramecium is the common observation of students every year. Either cells are seen dividing or swimming about in pairs. The dividing cells are reproducing by a process known as *fission*, which is the usual method (Fig. 70). The micronucleus divides first, then the cell divides through the middle of the macronucleus. A new mouth has to form on the posterior half and an extra contractile vacuole in each half. Woodruff has carried on a continuous series of observations upon the species of the paramecium known as *aurelia*, and this animal has been recorded as dividing for more than six thousand times by the process of fission. Each time that a paramecium divides there are no parents, but the individual parent has become merged into two offspring. In a species like *aurelia* it would seem as if one might almost say that it is immortal.

Conjugation.—In both species of paramecia that have been studied there are certain periods when two animals unite temporarily, during which there is a definite exchange of a fraction of the micronuclei. After each paramecium has thus received this small amount of nuclear substance the animals separate. Preceding this exchange of micronuclear material a complicated series of changes has taken place in the micronucleus of each. There appears to be a definite fusion between the micronucleus introduced into the paramecium and the portion that remains, with the result that a new micronucleus is formed. After this process, which some writers regard as similar to fertiliza-

tion in the higher animals, the cell divides by fission, but in this instance the new micronucleus has divided into four nuclei and the macronucleus has broken up into fragments which are gradually absorbed by the protoplasm of the cell. After the cell has thus divided there are two micronuclei in each half, one of which becomes a new macronucleus.

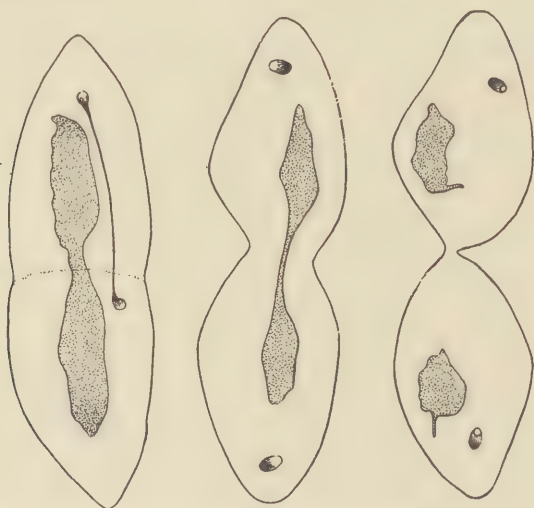


FIG. 70.—*Paramecium caudatum*, showing fission drawn from author's preparations. Notice the irregularity in the outline of the macronucleus which appears to be a normal feature.

Organic Movement.—In order that the paramecium may be able to carry on all of these vital activities, it must have been able to coördinate its movements. In an analysis of these movements it is customary to separate them into the following which are regarded as elementary properties of protoplasm: *Irritability*, which enables the protoplasm to respond to a stimulus; *conductivity*, by means of which the effect of the external stimulus is communicated to all parts of the cell; as these two properties respond the protoplasm contracts, which is the third property, *contractility*. These three are bound up in such a way that the animal is able to move in a definite direction; in other words, to correlate or coördinate its response to a definite stimulus. These are the same reactions that the frog is able to carry on by means of the nervous system and muscles. Jennings, page 261 states several important facts in regard to reaction of single-celled animals, two of which are quoted: "First, we find that

in organisms consisting of but a single cell, and having no nervous system, the behavior is regulated by all the different classes of conditions which regulate the behavior of higher animals. In other words, unicellular organisms react to all classes of stimuli to which higher animals react. Secondly, the reactions produced in unicellular organisms by stimuli are not the direct physical or chemical



FIG. 71.—*Ephelota bütschliana*, a budding individual with five daughter buds. *N*, macronucleus, which forms a branching organ connected throughout. Reproduction by budding is a form of fission. Notice the branching form of the macronucleus in each bud. (After Calkins.)

effects of the agents acting upon them, but are indirect reactions, produced through the release of certain forces already present in the organism. In this respect the reactions are comparable with those of the higher animals.”

Kinds of Paramecia.—In most cultures of paramecia there will be found animals which fall into two general classes: “(1) Caudatum

group (*Paramecium caudatum*). One micronucleus as seen in Fig. 70. Animals larger, slightly more slender, posterior half of body tapering more rapidly and regularly than in the aurelia group. (2) Aurelia group (*Paramecium aurelia*). Two micronuclei, unlike the one in caudatum. Animal smaller, slightly broader in proportion to length, and tapering less rapidly from the middle backward than in the caudatum group." (Jennings.)

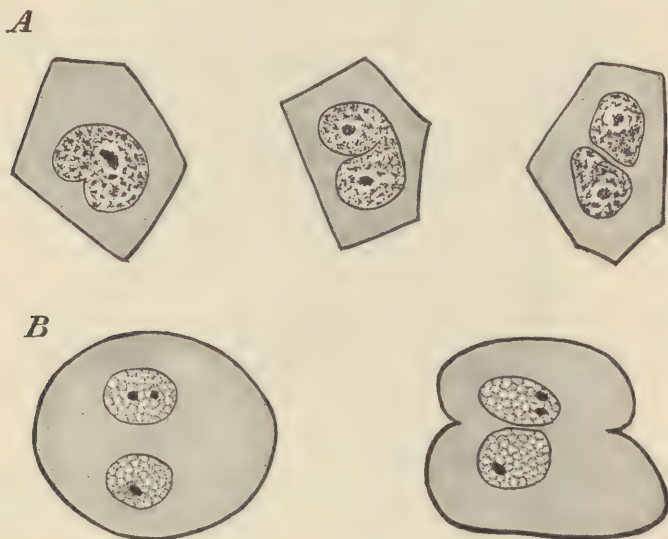


FIG. 72.—Amitotically dividing cells. The division of the cell by fission does not occur as commonly as the indirect method illustrated on page 76. These amitotically dividing cells show how the method of division known as fission takes place in cells in the higher animals. (After Child and Patterson.)

Protozoa.—The paramecium is a typical protozoan; some protozoa are simpler than the paramecium, others are more complex. There is a wide range of shape and size among the 8000 different species of protozoa. The relation which the paramecium bears to the various classes is shown in the table of classification (p. 301).

Protozoön Animals.—The study of the paramecium serves to show how an animal composed of only a single cell may carry on all of the necessary vital activities of the more complex animal such as the frog. The paramecium is an organism without any of the morphological structures which go to make up the bodies of higher animals. The whole life is lived within the limits of a single cell. In view of the fact that a single protozoön lives but a few hours and then divides, merging its individuality into two or more offspring, one

cannot use the term life cycle as it was used in the frog. But the protoplasm of which an individual is composed goes on generation after generation, and to these changes the term life cycle can be given.

In addition to the class infusoria of which paramecium is an example, there are the following with a few of the disease-causing species indicated.

Protozoa	Rhizopoda	<i>Amæba</i> . . .	{ <i>Amæba dysenteriae</i> <i>Amæba coli</i> <i>Amæba meleagridis</i> <i>Amæba buccalis</i>
		<i>Spirochæta</i> .	{ <i>Spirochæta obermeieri</i> <i>Spirochæta duttoni</i> <i>Spirochæta vincenti</i> <i>Spirochæta pallidula</i> <i>Spirochæta theileri</i> <i>Spirochæta gallinarum</i>
	Flagellata	<i>Trypanosoma</i>	{ <i>Trypanosoma gambiense</i> <i>Trypanosoma cruzi</i> <i>Trypanosoma bruzei</i> <i>Trypanosoma evansi</i> <i>Trypanosoma equinum</i> <i>Trypanosoma dimorphon</i> <i>Trypanosoma lewisi</i> <i>Trypanosoma equiperdum</i>
		Trypanoplasma Cercomonas Monas, etc.	
	Sporozoa	Hæmosporidia	{ Plasmodium { <i>Plasmodium vivax</i> <i>Plasmodium malaria</i> <i>Plasmodium falciparum</i> Proteosoma Hæmoproteus Hepatozoön, etc.
	Infusoria		

Biology of Cells.—The modern study of biology assumes an accurate knowledge of the general features of cell activity and cell structure. This study of the paramecium serves as an introduction to the biology of unicellular organisms. The next two chapters illustrate other phases of this same problem. The three combine to furnish the modern point of view in biology and serve as a background for the remainder of the book.

REFERENCES.

- CALKINS: Protozoölogy.
 JENNINGS: Behavior of the Lower Organisms.
 JENNINGS and HARGITT: Characteristics of the Diverse Races of Paramecium, Jour. Morphol., vol. xxi.
 WOODRUFF: Paramecium Aurelia and Paramecium Caudatum, Jour. Morphol., vol. xxii.
 WOODRUFF: Further Studies on the Life Cycle of the Paramecium, Biol. Bull., 1909, vol. xvii.

CHAPTER IX.

PLEUROCOCCUS—A PLANT CONSISTING OF A SINGLE CELL.

Habitat.—Everyone has noticed the greenish layer which occurs so commonly on tree trunks, moist rocks, wooden fences and similar objects. This layer is dull green in color and powdery in texture when dry, but when moistened by rain the color becomes brighter and the layer becomes somewhat slimy to the touch. Under the microscope this green material is found to be composed of thousands of very small cells or groups of cells of the plant pleurococcus. This plant is truly cosmopolitan in distribution, being found in the habitats mentioned in all parts of the world under the most diverse conditions of temperature and moisture. In north temperate regions it is usually found on the north face of vertical objects, *i. e.*, the shaded and moister side.

Morphology.—A single plant of pleurococcus consists of a spherical cell of variable size, ranging from 5 to 15 micra in diameter. Such separate plants are readily found; but more commonly they occur united into groups or colonies of two to a dozen or more cells. In such colonies the individual cells are not spherical but assume various irregular shapes because of the pressure of adjacent cells.

Each plant consists of a protoplast surrounded by a cell wall. The cell wall is thin and transparent and somewhat gelatinous on the outer surface; chemical tests show that it is composed of cellulose. It is non-living, therefore not a part of the protoplast; instead it is formed or secreted by the protoplast. The formation of such non-living cellulose walls is characteristic of plant protoplasts and occurs but rarely in animals.¹

The protoplast consists of a nucleus and one or sometimes two chloroplasts embedded in grayish or colorless cytoplasm. The nucleus lies near the center of the cell, is spherical in shape and measures from 2 to 4 micra in diameter; it contains one or more nucleoli

¹ In this chapter certain terms of current botanical usage are applied to both plants and animals; this seems desirable in order to facilitate comparison of the structures and processes of the two groups of organisms.

and shows a netted or reticulate structure which includes the chromatin. The chloroplast is bowl- or trough-shaped with the convex

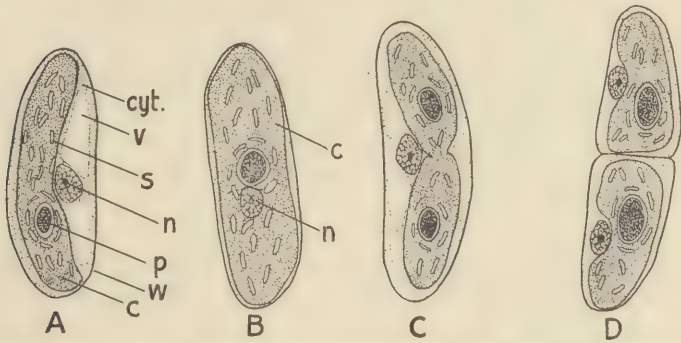


FIG. 73.—*Mesotetanium*, a unicellular green plant. *w*, cell wall; *cyt.*, cytoplasm; *v*, vacuole; *n*, nucleus; *c*, chloroplast; *p*, pyrenoid; *s*, starch grain. The chloroplast is a thick, curved plate; side and top views of it are shown in *A* and *B*. *C*, *D*, stages in reproduction by cell division. $\times 1070$.

surface outward; it lies near the surface of the protoplast but is wholly surrounded by cytoplasm. In an isolated plant of spherical

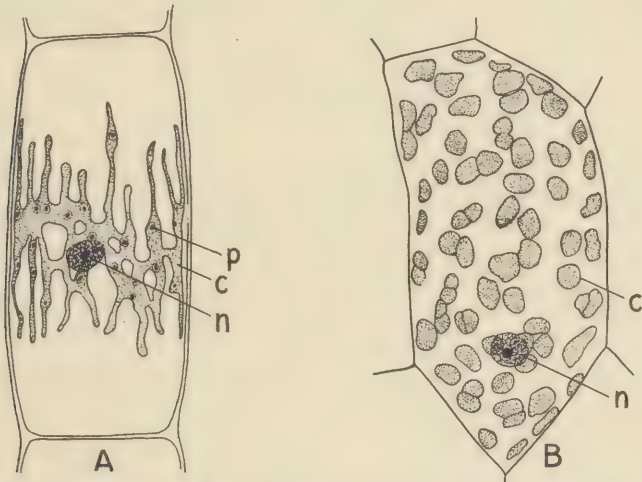


FIG. 74.—Surface views of plant cells, showing different forms of chloroplast. *c*, chloroplast; *p*, pyrenoid; *n*, nucleus. *A*, cell of *Draparnaldia*, with single elaborate chloroplast; *B*, cell of fern prothallium with many simple chloroplasts. $\times 680$.

shape it may almost entirely surround the nucleus; but in cells which form part of a colony it is smaller and assumes a position in

the curved part of the cell, *i. e.*, in the part most immediately exposed to light. The chloroplast of a living plant of pleurococcus is bright green in color, due to the presence within it of the pigment chlorophyll. If the cells are placed in alcohol the chlorophyll is dissolved out; the chloroplast is seen to be unchanged except in color, which is now grayish, while the chlorophyll, if present in sufficient quantity, colors the alcohol a characteristic green. It is important to note this distinction between the chloroplast, which is a living organ of the protoplast, and the chlorophyll, which is a green pigment contained in the chloroplast.

Photosynthesis.—As already explained (page 36) the food of animals consists for the most part of organic substances of three groups: carbohydrates, proteins and fats. The same is true of plants, and we may therefore say that the food of all organisms is essentially the same and consists of organic substances of the three groups named. But if we examine the source of the food of an animal, *e. g.*, the frog, we find that all of it is derived from other organisms—insects, worms, plants, etc. Hence such organisms as the frog are dependent, or, as we say for plants, heterotrophic in nutrition, *i. e.*, they are dependent upon other organisms for food. If, on the other hand, we study the nutrition of a green plant such as the pleurococcus it becomes plain that its food is not brought in from outside the organism but is manufactured *in situ* from inorganic materials. Such organisms are independent or autotrophic in nutrition, *i. e.*, they are capable of manufacturing their own food and so are independent of other organisms.

In general, green plants are autotrophic; conversely, plants lacking chlorophyll, such as mushrooms, etc., and all animals are heterotrophic. In short, with the exception of a few bacteria all autotrophic organisms possess chlorophyll and owe their power of food manufacture to it; and all other organisms secure their food directly or indirectly from the autotrophic ones.

Chlorophyll is formed only within chloroplasts except in the simplest green plants (Schizophyceæ), where chloroplasts are lacking and the chlorophyll is distributed throughout the protoplast. It is readily soluble in alcohol, ether, benzol and other reagents; the solution shows the characteristic green color by transmitted light, but under strong reflected light appears a deep blood red. Chemically, chlorophyll is a complex compound of carbon, hydrogen, oxygen, nitrogen and magnesium; its probable empirical formula is given by one investigator as $C_{54}H_{72}O_6N_4Mg$. While not a constituent of

chlorophyll, iron is always present in the chloroplast and seems to be essential to chlorophyll formation. Either in solution or in the living plant chlorophyll absorbs part of the light which falls upon it. As shown by the spectroscope, this absorbed light consists of a series of rays of various wave-lengths; but for the most part the absorption is of the red-orange and blue-violet rays while the yellow-green rays are transmitted unhindered. The energy of the light thus absorbed in the chloroplasts is available for the work of the plant and is used to bring about the manufacture of food. Obviously, therefore, the process can go on only in the presence of the light necessary to afford the energy, *i. e.*, in nature, in the daytime.

The materials from which carbohydrate food is manufactured by green plants are two in number, carbon dioxide and water. Carbon dioxide is present in the atmosphere in the small but constant concentration of about 4 parts per 10,000 parts of air, and is therefore readily available to such plants as the pleurococcus. Water is

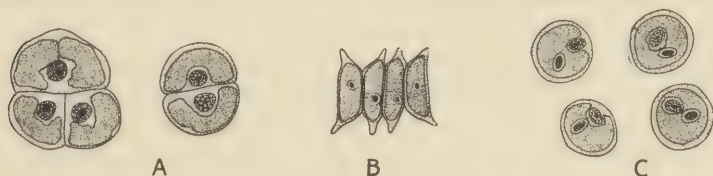


FIG. 75.—Colonies of various unicellular green plants. *A*, *pleurococcus*, *B*, *scenedesmus*; *C*, *tetraspora*. $\times 800$.

absorbed directly from the substratum through the cell wall into the protoplast. The carbon dioxide taken in is dissolved in the water in which it is readily soluble. While the exact steps in the process of formation of carbohydrate foods from these substances are not yet clear the essential facts are well established. The carbon dioxide and water are partially or completely reduced to their elements, which immediately recombine to form a monosaccharide sugar (probably dextrose) with the freeing of oxygen. These two processes are represented by the reaction $6\text{CO}_2 + 6\text{H}_2\text{O} = \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$. The oxygen is given off into the atmosphere through the cell wall. The sugar is the primary food of the plant, being the principal material used in the synthesis of other foods and in the processes of metabolism. When it is produced in excess of the immediate requirements a further reaction takes place by which some of the water is eliminated and the sugar is "condensed" in starch; this reaction is $n(\text{C}_6\text{H}_{12}\text{O}_6) = (\text{C}_6\text{H}_{10}\text{O}_5)_n + n(\text{H}_2\text{O})$.

This starch is deposited in the chloroplast as granules or "starch grains" and forms a reserve food supply for the cell; in green plants kept in darkness the starch grains soon disappear and reappear only after the plant has again been in the light for a considerable period of time. In some plants, *e. g.*, *vaucheria*, the excess food is stored in the form of a fat or oil, but it is probable that here also the first food formed is a sugar.

This process by which carbohydrates are manufactured in green plants is called photosynthesis; its essential features are summarized as follows: The materials used are carbon dioxide and water; the energy is obtained from sunlight absorbed by chlorophyll; the chloroplast by the use of this energy brings about a chemical synthesis of the materials, resulting in the freeing of oxygen and the production of a sugar, some of which is usually transformed into starch and stored in that form.

Other Materials and Syntheses.—In the life processes of green plants certain mineral substances are necessary in addition to the carbohydrates produced by photosynthesis. As mentioned above, magnesium is a constituent of chlorophyll, and iron is always present in the chloroplast; these elements are therefore essential to the metabolism of green plants. In addition to these, nitrogen, potassium, phosphorus, calcium and sulphur are required by most plants. In the case of simple forms like the *pleurococcus* the very minute quantities of these that are necessary are contained in the form of soluble compounds in the water taken in. From the sugar produced by photosynthesis, together with nitrogen and sulphur taken in in this way, various proteins are produced by the living protoplast. The details of protein synthesis in plants are for the most part unknown, but the process is probably enzymatic in character. By similar processes fats are also formed from carbohydrates. This occurs in the *pleurococcus* especially at periods when the plants have become very dry and are in an inactive or resting condition; at such times little or no starch is formed while fats are present in quantity.

Metabolism.—As already defined (page 47), metabolism includes all the processes which have to do with the use of food by the organism. These processes in simple plants, such as the *pleurococcus*, differ in no essential features from the corresponding processes in the *paramecium* and other simple animals. The foods produced by the processes just described are assimilated by the protoplast, resulting in the formation of new protoplasm and consequent growth of the cell. Similarly, the process of respiration takes place continually in

the pleurococcus as in all other organisms, resulting in the formation of carbon dioxide and water and the releasing of the energy necessary for all the life processes of the protoplast, except photosynthesis (page 100).

Reproduction.—As a result of the assimilation of food, growth of all parts of the cell results. The cell wall is elastic and is stretched by the increased volume of the protoplast; its normal thickness is maintained by the deposition upon its inner surface of new layers of cellulose by the protoplast. The chloroplast also enlarges and ultimately divides into two. The nucleus enlarges for a time, then divides mitotically (page 74). A cell wall is formed between the two daughter nuclei, dividing the original cell into two similar cells, each containing cytoplasm, a nucleus and a chloroplast. The newly formed cells may separate at once or they may adhere for a time, forming groups or colonies of cells. This simple division of the original plant to form two plants is the only form of reproduction known to occur in the pleurococcus.

Other Unicellular Green Plants.—Microscopic examination of water from ponds, streams or laboratory aquaria will usually show some forms of unicellular green plants. Especially common in aquarium jars is *Scenedesmus*, with spindle-shaped cells grouped in colonies of four. Pond waters usually contain numerous desmids (*Closterium*, *Cosmarium*, etc.), which are characterized by curiously shaped bilaterally symmetrical cells with very complex chloroplasts. Diatoms, with cell walls of silica instead of cellulose, and containing a brown pigment in addition to chlorophyll, are abundant in all waters and moist places.

CHAPTER X.

BIOLOGY OF BACTERIA AND YEAST—THE SIMPLEST LIVING ORGANISMS.

Organized Ferments.—This chapter is limited to a general survey of the more important of the so-called organized ferments. This expression was applied at first to such forms of cell life as have the ferment associated with the life of the cell, and in one sense the term organized ferments may be retained, since in Nature these intracellular¹ enzymes are found acting through the living protoplasm that produces them. They are not poured out as is the saliva or the pepsin, which may be described as extracellular enzymes. It was believed for many years that these ferments could not be separated from the protoplasm which produced them and that their ferment action ceased with the death of the protoplasm. Buchner demonstrated that yeast could be ground with infusorial earth and a juice extracted which had the power to cause alcoholic fermentation. The yeast plant may be killed by alcohol, ether or acetone and still retain its power to cause fermentation. In a similar manner the bacteria which cause lactic acid in milk can be killed, so that they do not grow or divide, and yet they can form lactic acid. These experiments are difficult to perform, but are valuable as showing that the enzymes are to be classed as similar to those found in the higher animals and plants.

Yeast.—The word yeast is a general name for a half-dozen or more distinct species of plants found growing wild and cultivated. Because yeasts feed upon sugar the term *saccharomycetes* is given them. These plants are necessary in bread-making and in the manufacture of liquors. If yeast is to grow and thrive the temperature may range from 9° to 60° C. When dried it can endure a higher temperature, but it requires a definite environment if it is to live.

Morphology of Yeast.—If a small amount of compressed yeast is mixed with water and then examined with the microscope a large

¹ Vernon: *Intracellular Enzymes*, 1908.

number of oval and egg-shaped bodies are seen. The majority are either unicellular or have small buds attached. Sometimes a short chain of buds is noted. There is a definite cell wall composed of "yeast cellulose." The living protoplasm is granular and usually contains a number of vacuoles filled with sap. The beginning student frequently mistakes the sap vacuoles for the nucleus. Many minute glistening dots can be made out which are probably fat. No chlorophyll or starch is found in the protoplasm. The nucleus is a coarsely granular body and can be differentiated by the use of proper stains.



FIG. 76.—Yeast cell showing nucleus. Work out the method of budding in the laboratory.

Reproduction of Yeast.—The usual process of reproduction is easily seen in any study of yeast in water. The method is similar to fission in protozoa, except that there is a large parent mass and a small offspring. The nucleus divides by amitosis and the bud remains attached for some time. Occasionally yeast exhibits the formation of spores by a process which results in dividing the protoplasm of the cell into two, three or four distinct masses. When the old cell wall breaks down under proper environmental conditions each spore is capable of starting a new series of yeast plants.

Food of Yeast.—Pasteur devised a solution which contains no organic nitrogenous matter; the nitrogen is in a more complex compound than the nitrates, which are utilized by green plants (page 100).

Water, H_2O	83.76 per cent.
Cane-sugar, $C_{12}H_{22}O_{11}$	15.00 "
Ammonium tartrate $(NH_4)_2C_4H_4O_6$	1.00 "
Potassium phosphate, K_3PO_4	0.20 "
Calcium phosphate, $Ca_3(PO_4)_2$	0.02 "
Magnesium sulphate, $MgSO_4$	0.02 "
	100.00 "

The yeast is able to grow in this fluid and to make more protoplasm; it must therefore have been able to utilize inorganic material as the whole source of its food energy. This is a physiological property that is probably lacking in the unicellular animals, although some recent researches assign a rather higher synthetic power to animals. The green plant cells are able to utilize simpler nitrogen compounds than is the yeast, so that the yeast occupies an intermediate position between animal and green plant cells in its ability to manufacture its own food out of the raw elements. It can use nitrogen in the higher forms of proteins, and in this sense approaches more closely to the animal cell. Free oxygen is as necessary to yeast as to other forms of living matter. The anaërobic bacteria such as the intestinal bacilli and many others are exceptions to this general statement.

Metabolism.—The yeast plant is able to build up its own food from the mineral substances furnished in Pasteur's solution and to utilize them in the making of more yeast protoplasm. The series of changes through which foods must pass in becoming living protoplasm we must believe are similar in all forms of life. There is then in the yeast plant digestion of foods by intracellular enzymes. It is probable that there is a separate form of enzyme for the protein digestion and another for the carbohydrate. The digestion of the foods must be followed by a series of up-building stages which finally result in the food becoming protoplasm. The yeast does work in growing new cells and causing fermentation, as in bread, where the temperature is raised by the fermentation process. This requires energy and is an outgo from the cell. To this may be added carbon dioxide and nitrogenous wastes, although these wastes are masked in part by the presence of other substances in the culture solution.

BACTERIA.

Relationships.—There has been much discussion in the past as to the general relation of the bacteria, whether they should be grouped with the plants or the animals. They are related more closely to a group of algæ known as the blue-green algæ than to any other definite group of plants or animals. Their method of locomotion, and in some instances the manner of spore formation, reveals well-recognized protozoan traits. In the main they are best regarded as plants because of their usual power of living without already prepared protein food and because of their method of reproduction. In their

general physiology they are more like fungus plants and so are classed under the fungus term (mycetes) as *schizomycetes*.

Morphology.—Bacteria appear in three general shapes—the straight rod (bacillus), the bent rod (spirillum) and the sphere (coccus or micrococcus). “There are spherical forms of wide difference in sphericity, rod forms with great variation in length and diameter, and spiral forms having from a fraction of one spiral to many spirals. Furthermore, spherical forms may become piled upon one another so that colonies result, and rods may be jointed in such a way as to construct filaments. Within these groups many species of bacteria are known. One high authority, Migula, considers that there are 1272 distinct species of bacteria, most of which belong to the bacillus type.” (Bergey and Caldwell.) Some single species such as *Bacteria*

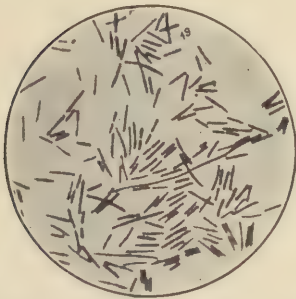


FIG. 77.—Long slender bacilli. $\times 1000$ diameters. (After Park.)

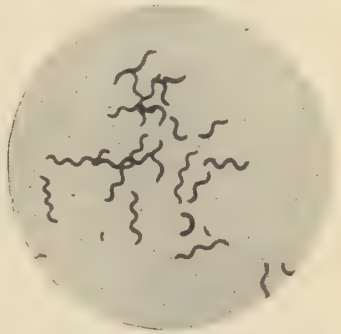


FIG. 78.—Very large spirilla. (After Park.)

pestis and *Bacteria diphtheriæ* exhibit considerable variation when studied under different conditions of growth, appearing first in one shape then in another. Such changes are, however, never permanent, but they illustrate the fact that the morphology of bacteria is not a safe method upon which to determine species.

Size.—“The bacteria were formerly spoken of as the smallest of living things, but since the recognition of ultramicroscopic organisms it is necessary to be more specific in characterizing their dimensions. The unit of measurement in microscopy is the micron (μ) or micro-millimeter. This is 0.001 of a millimeter or approximately $\frac{1}{25000}$ of an inch. Applying this unit to bacteria we find that the micrococci and the short diameter of the bacilli and spirilla average about 1μ . The micrococci vary in diameter from a small fraction of a

micron to 3 or 4 μ . The bacilli are sometimes very small, as the influenza bacterium, with a width of 0.2 μ and a length of 0.5 μ , and sometimes very large, as for example the *Bacteria anthrax*, with a width of 0.2 μ and a length of 5.2 μ . The spirilla average about 1 μ in diameter, but may be as long as 30 or 40 μ ." (Frost.)

Structure.—Bacteria are extremely simple plants and are regarded by many as the simplest known living things. The cell wall is usually surrounded by a slimy or gelatinous capsule and is not like the cell wall of the higher plants, which is composed of cellulose. Their diminutive size prevents one from learning very much about the cytoplasm. There is no distinct nucleus. The essential part of this organ is believed to be represented by certain granules. From the cell wall in some species a number of cilia or flagella project which are used in locomotion.



FIG. 79

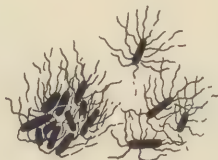


FIG. 80



FIG. 81

FIGS. 79, 80 and 81.—Fig. 79, spiral forms with a flagellum at only one end; Fig. 80, bacillus of typhoid fever with flagella given off from all sides; Fig. 81, large spirals from stagnant water with wisps of flagella at their ends (*Spirillum undula*). (After Abbott.)

Motility.—The organs of locomotion are used by the bacteria in moving from place to place. "Some dart with great rapidity, others move slowly; some move in straight lines, others wobble, but any particular character is quite constant, and many of the bacteria may be recognized by their characteristic movements. Their rate of movement varies greatly with the species. As they are viewed under the microscope their motion seems very rapid. The typhoid bacillus has been estimated to travel 2000 times its own length in an hour, while the cholera spirillum may go 45 times as fast. It is probable that their rate is relatively little greater than that of a trotting horse."

Reproduction.—"This is accomplished by means of binary fission. When a bacterium has reached maturity fission begins. This change in the cell is not customarily regarded as preceded by any

series of changes comparable to karyokinesis (mitosis) in the higher cells, since no nucleus in the ordinary sense has been demonstrated in the bacterial cell. Division begins by an invagination of the protoplasm in the middle of the cell, which proceeds until the cell protoplasm is completely separated. The cell wall then grows in and finally splits, forming the two ends of the new cells. These new cell walls are formed at right angles with the long axis of the cell in the case of the bacilli and spirilla, except in rare instances. In the case of micrococci the throwing of the cell wall across one diameter is quite as economical as any other and may therefore proceed in any direction. Migula makes a considerable point of the fact that bacilli and spirilla elongate before division and micrococci divide before they elongate, and this is the criterion which he would use to separate these two-form types. A generation among the bacteria is from one division of the cell to another. This is sometimes very short, in fact, only twenty to thirty minutes. Many of the bacteria after a half-hour's time have grown from newly formed cells to maturity and are ready to divide again. This makes it possible for bacteria to multiply with great rapidity, and if we know the length of the generation in a particular bacterium it is easy enough to estimate the rate of multiplication, at least theoretically. It is, of course, quite impossible for the bacteria to maintain their theoretical rate of growth for any length of time because of the formation of by-products, but they grow with enormous rapidity, as is shown in cultures and in the changes which they bring about in nature, such as the production of fermentation and the generation of toxins." (Frost.)

Under certain conditions a considerable number of bacteria form spores (endospores). The protoplasm is broken up into a number of bodies within the cell, which are then called endospores. Their chief value seems to be to enable the bacteria to undergo unusual and unfavorable conditions. In this condition bacteria possess remarkable powers of resistance.

Zoöglea.—The mother of vinegar illustrates a special habit of certain bacteria. The cells secrete a mucilaginous substance that causes them to cohere in great numbers. In some instances this condition represents a stage in the life history, while in the vinegar it is induced by the formation of a certain amount of acetic acid.

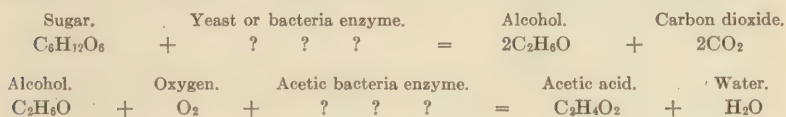
Metabolism.—Fischer divided bacteria into three groups, according to the nature of their metabolism. (1) Bacteria which are like the green plants in requiring neither organic carbon nor organic nitrogen.

These are the so-called prototrophic bacteria, which possess the remarkable property of being able to build up both carbohydrates and protein out of carbon dioxide and inorganic salts (page 100). (2) Bacteria which need organic carbon and nitrogenous compounds. These are called the metatrophic bacteria. (3) The paratrophic bacteria which live as true parasites and can exist only within the living tissue. This group cannot manufacture their own food and are like animals in this respect. The metabolism of bacteria may then show all of the phases already described for green plant cells and for animal cells as well as certain additional phases. The food is absorbed directly through the cell wall and is as varied as is their habitat. There seems to be no form of organic substance living or dead that may not serve as a source of food supply for bacteria, so that the enumeration of their foods becomes practically impossible. A special phase of the metabolism of bacteria is illustrated in their relation to nitrogen compounds. Nitrogen in an uncombined state cannot be used as food energy by most plants. It is obvious that the amount of ammonia, nitrites and nitrates would soon become exhausted unless there were some way of supplying more of the nitrogen compounds. Many of the soil bacteria are prototrophic in habit and carry on the important work of combining the free nitrogen into a form that can be used by other organisms. The several nitrogen combinations are effected through the agency of several kinds of bacteria. There are also bacteria which live in the roots of certain plants, like clover, beans and peas, which are able to utilize the nitrogen of the air. All of the higher forms of plants and all of the animals are dependent upon microscopic bacteria for their nitrogen. It would be very strange if the character of metabolism which is so fundamental in living things should be essentially different in bacteria; it probably is not, and so the usual steps in assimilation and dissimilation may be assumed to take place in bacteria. During this process enzymes are utilized and toxins produced.

Enzymes and Toxins.—"Among the most interesting and least understood products of microbial action are the enzymes and the toxins. These two groups are related in many respects. Toxins and enzymes are formed by the cells in such small quantities that they would never have been discovered by ordinary chemical means were it not for the unusual effects which they produce, the enzyme acting upon food substance and the toxins acting physiologically upon organisms. Toxins and enzymes are chemically unknown." (Hahn.)

Zoötoxia of the rattlesnake is the best-known animal toxin, while phytotoxins in plants are more common. Toxins and enzymes are both very sensitive to heat, light and certain chemicals. Both of these bodies must be defined in terms of what they do.

Fermentation.—The organized ferments all employ the same general method to effect changes in the substances upon which they act. The change due to these minute plants, bacteria and yeast is very great, and yet it can nearly all be reduced to a process of fermentation. In the ordinary processes of fermentation the chemical compound is simplified. This is easily understood from the following:



In this transformation through the action of the yeast enzyme and acetic bacteria enzyme the sugar molecule has become much simpler and the ultimate result is a substance entirely different from sugar, namely, vinegar. The changes are chemical in their nature. It is difficult to make any classification of ferments that is not open to criticism. There are the intracellular and extracellular enzymes that act upon the carbohydrates, proteins and fats; these with the oxidizing and reducing enzymes may serve, however, to give a working classification.

CHAPTER XI.

WHAT IS LIFE?

IN the study of the living frog there was no question but that it was alive because it was able to move. It was also possible to observe a number of other life processes in the frog; such as breathing, eating, reproduction, etc. The paramecium studied next was obviously alive for the same reasons. It was more difficult to detect these same vital activities in the simple green plant cell but still they could be made out. In the yeast and bacteria it was found that some of the vital processes were neither clearly like the animal nor like green plants but rather of a more primitive nature. This primitiveness of some of the vital processes in bacteria has led recent writers to declare that bacteria represent the most primitive forms of life.

New frogs were seen to develop from frog eggs the paramecium divided and new paramecia resulted. In a similar manner new plants come into existence. The observations of the past forty years have conclusively shown that no new organism has been produced except through the influence of a previously existing like organism. This is an established generalization in biology and is known by the term *biogenesis*—*the theory that life is generated from living beings only*.

Spontaneous Generation or Abiogenesis.—The view that life could come into being without the influences of preëxisting life or from inorganic matter was held for some twenty centuries beginning with Aristotle, 325 B.C., to Tyndall, 1876. For the ancients there was no difficulty in explaining the occurrence of new animals as complex as insects or even fish. The grotesque extremes to which this easy way of accounting for living things was carried is illustrated by both Virgil and Ovid, who described bees swarming forth from the putrid bowels of the recently killed steer. Frogs, toads, rats and fish were easily conjured from the mud of ponds and streams by the vivifying action of the heat of the sun. Among children and ignorant persons there still lingers a belief that a horsehair placed in water may become a living worm, as well as other similar crude notions about the origin of living things. This idea that life

could not come from non-living matter was first successfully questioned by Redi, 1680, who proved that maggots would not grow in meat if the flies were prevented from laying their eggs on the meat. Huxley says of Redi, "The extreme simplicity of his experiments and the clearness of his arguments gained for his views and for their consequences almost universal acceptance."

Seven years after the experiments of Redi, microscopic animals and plants were discovered and the theory of spontaneous generation took on a new lease of life, as it was used now as an explanation for these minute forms of life. The Italian, Spallanzani, 1777, the Frenchman, Pasteur, 1864, and the Englishman, Tyndall, 1876, are the three great men who successfully devised experiments that conclusively demonstrated that microorganisms did not arise spontaneously. These experiments which established the theory of biogenesis for all the forms of life which are known to science should be read in this connection. (See references at close of chapter.)

There is no longer any controversy among scientific men as to how present-day animals and plants came into existence, for they can be proved to have been derived biogenetically. But there still remains the question of the first origin of life or whether it arose more than once as the cooling earth took shape. There have been a number of attempts to answer these last two questions, but up to the present there is no way of knowing what may have happened in the prehistoric ages of geologic history, where the earliest records of life are found.

There is still much to be learned about living protoplasm, and while it is possible that man may not completely solve all of the mysteries locked up within the body of a paramecium, it is desirable to keep on investigating. At present protoplasm is being studied from the chemical, physical and biological points of view, each of which is briefly summarized in the following pages.

Chemical Composition of Living Matter.—When life is studied from the chemical point of view the results tell us what chemical bodies are present. No one has been able to write the chemical formula for living matter, and after all these years but little is known of the chemistry of living matter. One of the reasons for this lack of chemical knowledge is that as soon as a chemical analysis is applied to living protoplasm it becomes dead, and science has yet to prove that the chemistry of dead protoplasm is the same as that of living protoplasm. Whether future research reveals that dead and living protoplasm are essentially the same or not, we already know what chemical elements occur in protoplasm.

There are some eighty-two different chemical elements known to science and not more than twenty-nine of these ever occur in living protoplasm. Twelve of these are but rarely found while four are of frequent occurrence. The remaining thirteen are invariably found and believed to be essential to life. These are hydrogen, carbon, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, iron, sodium, chlorine and silicon. These elements are the most numerous in the rocks, water and atmosphere. But the amount of these elements, even those that are essential to life, found in an organism bears no relation to their abundance in nature.

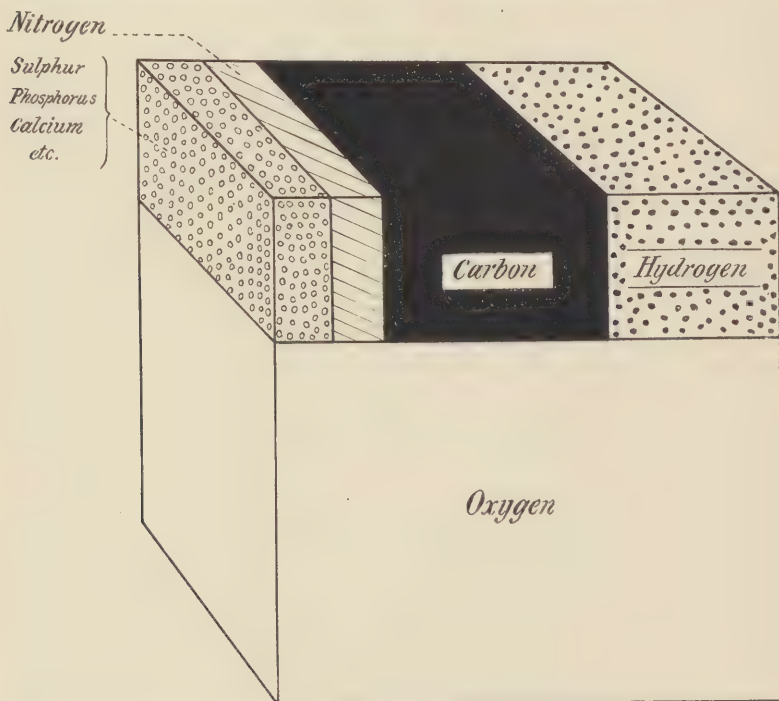


FIG. 82.—Diagram to show the proportionate amounts of the chemical elements in living things.

The following summarized account from Starling of the most important elements shows their relations in Nature: "Carbon forms the greater part by weight of the solid constituents of living protoplasm. In the inorganic world practically all of the carbon occurs in a completely oxidized form, namely, carbon dioxide. A small amount, 4 parts in 10,000, is present in the atmosphere, while vast

quantities are buried in the crust of the earth as carbonates. Practically all of the carbon in organic tissues is derived from the minute proportions of carbon dioxide present in the atmosphere. This is combined through the work of the chlorophyll into carbon compounds that can furnish energy to living matter. Hydrogen exists almost exclusively in the form of water. In this form it is taken up by plants and animals, with the exception of a small amount absorbed in the form of ammonia. Oxygen is the only element which, in all the higher organisms, at any rate, is taken up in the free state. It forms one-fifth of the atmosphere, and, as the oxides of the various metals, a considerable fraction of the earth's crust; it takes a position apart from the other foodstuffs in that its presence is the essential condition for the utilization of their potential energy. Nitrogen constitutes four-fifths of the surrounding atmosphere and can be utilized by most plants only in the form of ammonia, nitrites or nitrates. To animals these compounds are useless and the only source of nitrogen for this class is protein. Sulphur is found in all soils in the form of sulphates, in which form it can be taken up by plants. Iron, though forming but a minute proportion of the material basis of living organisms, is, nevertheless, indispensable for the maintenance of life. Phosphorus is absorbed by the plant as phosphates."

Of the thirteen elements always found in protoplasm, six are more abundant. These are the ones that make up the structure of the protein and carbohydrate molecules. Carbon, hydrogen and oxygen are the only ones that are found in that part of organic foods classed as fats and carbohydrates. The protein molecule is much more complex and only empirical formulas can be given, but in these there always occur carbon, hydrogen, nitrogen, oxygen and sulphur. One of the simplest plant proteins, the crystalline vitelline of the squash, is written $C_{292}H_{481}N_{90}O_{83}S_2$, while the form of the animal protein, hemoglobin, is supposed to be about $C_{712}H_{1130}N_{214}O_{245}FeS_2$. Through the foods containing these chemical elements, organisms secure most of their energy for growth and bodily maintenance. The remaining elements found in protoplasm exist in small quantities and are usually brought to the living protoplasm in the water. It may be said that carbon, hydrogen, nitrogen and oxygen are the most important of the elements found in protoplasm because living protoplasm must be constantly supplied with foods chiefly composed of them.

The chemical composition of protoplasm helps one to appreciate

how the energy locked up in the various foods may yield a certain amount of energy to the protoplasm. When a chemical molecule of starch or albumin or even molecular oxygen is utilized by protoplasm a given amount of energy is believed to be rendered available, but it should be kept clearly in mind that when these chemical bodies unite organically they do not produce a body like themselves and with properties like themselves, but something entirely distinct, namely, protoplasm. This important point is further outlined under the heading, the Biological Properties of Protoplasm.

The Physical Properties of Protoplasm.—When protoplasm is studied by means of the microscope, it presents a certain appearance. This will vary with the kind of protoplasm being studied and whether it is alive or has been fixed by such chemical agents as picric acid, formalin, etc. Up to the present it has been impossible to give a single physical description of protoplasm that applies to plant and animal, muscle and nerve, or egg and gland cell protoplasm. The physical picture presented by protoplasm under different conditions of activity and in different organisms has been accounted for by the two following theories:

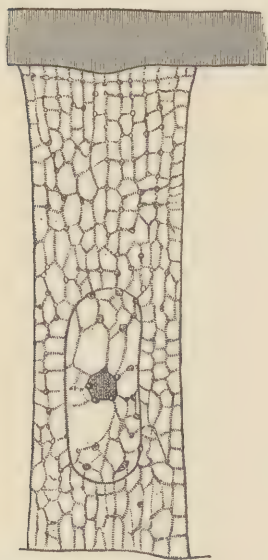


FIG. 83.—Epidermal cell of an earthworm. $\times 3000$. (After Hall.)

1. *Fibrillar Theory*.—The adherents to this theory claim that a distinct meshwork of cytoplasmic fibrils can be made out when suitable treatment is employed, and such terms as spongioplasm, reticulum, filar substances, etc., are used to describe the meshwork. Filling in the meshes there is a structureless sap-like substance. For some cells and for certain phases of cell activity the fibrillar theory adequately describes the structural conditions of the protoplasm.

2. *The Alveolar Theory of Bütschli*.—This theory assumes that protoplasm consists of two fluids, one suspended in the other. The fluid that is suspended is made up of numerous minute drops which give the appearance of closed chambers or alveoli. The containing

fluid is continuous and occurs between these minute alveoli. By mixing rancid oil with sodium carbonate a solution is produced

that imitates the appearance of protoplasm very closely. The epidermal cell of an earthworm (Fig. 83) is an illustration of alveolar cytoplasm.

In nearly all forms of protoplasm there are variously shaped granules which are the usual particles seen by students. Some of these become so large as to be the most conspicuous physical feature (Fig. 84). We may say that protoplasm consists of an aggregate of fluids which vary in density and which present a wide variety in appearance.¹

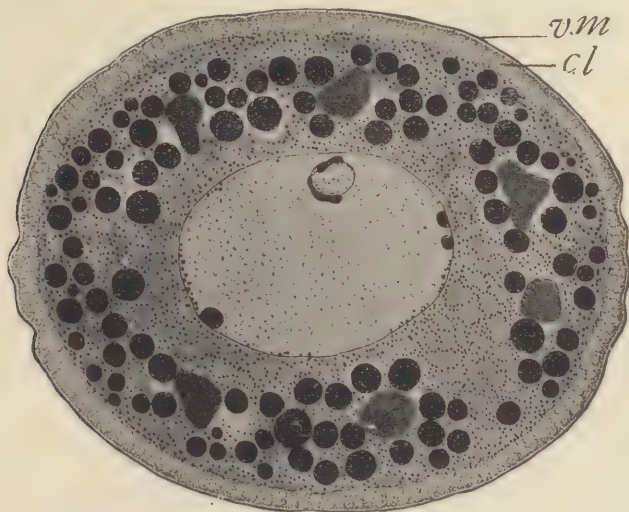


FIG. 84.—Section of the egg of *Nereis*, fixed in Meves's fluid five minutes after insemination. The cortical layer is somewhat reduced. *c.l.*, cortical layer; *v.m.*, vitelline membrane. Note the several kinds of bodies in the cytoplasm. (From Lillie, in *Journal of Morphology*.)

The Biological Properties of Protoplasm.—Neither the chemical composition nor the physical appearance of protoplasm furnishes an explanation of living protoplasm. As already stated, when chemical bodies unite to form protoplasm there is produced a substance which has certain properties or characteristics that enable one to distinguish between that which is alive and that which is not. These are defined under the following eight headings:

1. *Relation of Life to the Living Body.*—Life does not reside in any one structure in the body of plants and animals but is present in all of their parts. It cannot be measured, photographed or weighed.

¹ For a recent discussion of the relation of colloids to protoplasm, read Matthews' *Physiological Chemistry*, chapter v, p. 190.

Even a child can tell a dead animal from a live one, but no one can isolate that which makes an organic being living. This general diffused, immaterial condition, life, may be driven from the organism



FIG. 85.—Redwood trees in the foreground with sugar pine, bull pine and white fir in the background, Sierra National Forest, California. The redwood trees are the oldest and largest living things known to science. Illustration furnished by the United States National Museum and published with their permission.

by a multitude of causes and leave all of the parts intact, as when life was present—in some instances the several parts may remain alive for hours or days after life has departed. This is well illustrated by taking the heart of a frog from the recently chloroformed animal

and placing it in salt water. The heart now begins to beat in a rhythmic fashion. Living cells can be taken from various animals, and when placed in an artificial culture can be kept alive for months at a time. In one instance connective-tissue cells isolated from the heart of a chick embryo have been kept alive for seven years. Under such conditions they are entirely separated from the living animal; but while able to grow under this abnormal condition, they cannot give rise to a new individual like the animal or plant from which they were taken.

2. *Size of Living Bodies.*—The size and shape of living bodies cannot be stated in any general expression. Some are so small that the highest power of the microscope has failed to reveal them, while the giant redwood trees tower above all other living things by many feet (Fig. 85). Between these two extremes are found a multitude of sizes, each of which is characteristic of a given species. Animals have never grown to such large size as some of the trees, although some of the fossil forms were nearly one hundred feet long (Fig. 85). When a given kind of plant or animal comes to have a certain size and shape there are only minor variations from year to year, as both appear to have become fixed for a given species and are continued from generation to generation by heredity.

3. *Age of Living Bodies.*—A number of the unicellular organisms retain their individuality for not more than thirty minutes under normal feeding conditions, while the great redwood trees have retained their individuality for possibly twenty centuries, and between these two extremes are to be found all gradations. It is customary to speak of the longevity of a group of plants in such terms as annuals or perennials, which means that certain species have come to have a certain fixed period during which they live. One of the real problems in biology is to explain old age. It is now conceded that this is a natural stage in the life of all organisms; but why should one come to have the ability to live for centuries and a closely related form but a hundred years? All organisms pass through three stages—youth, maturity and old age—which are intimately associated with organic maintenance, but even when the body is supplied with suitable food it grows old.

4. *The Cell and Living Protoplasm.*—The accumulated observations of all the scientists clearly demonstrate that life is to be found only in protoplasm; and also, that this protoplasm is always to be found existing in structures of definite size and shape, to which the name cell has been given (page 56). This is one of the most

obvious facts thus far established in this course (see also Heredity, page 269).

5. *Reproduction and Life*.—All of the observations of man indicate that new forms of life are produced by living organisms. In so far as the present varied life is concerned, each species of plant and animal is produced by parent forms of the same species. Reproduction, while a universal process in life, has become highly specialized, so that only a frog can come from frog eggs and *Rana pipiens* cannot be derived from *Rana catesbiana*, although both of these frogs belong to the same family, the *Ranidæ* (page 21).



FIG. 86.—*Diplodocus carnegii* Hatcher, from modelled restoration by C. W. Gilmore. This reptile was probably 87 feet long and 15 or 16 feet high at the hips. One of the largest animals thus far known to science. Although this huge animal is known only through a study of its fossil remains, it can be confidently stated that it possessed all of the fundamental characteristics of modern animals. Photograph furnished by the United States National Museum and published with their permission.

6. *Growth and Life*.—Growth is one of the facts of life that all have observed. When the frog was dissected a number of important organs were found. Where did these come from? During the embryonic growth of the frog all of these structures gradually took shape and position in the body of the frog. Inasmuch as the term growth is used to describe the formation of crystals, it is desirable to specify its use in biology: (1) Crystals grow only in a highly saturated solution of material like the crystal itself, while living things can grow in a weak nutritive solution; (2) this nutritive solution does not contain the chemical compounds found in the living cell, while in the case of crystals the substance of the crystal and its nutritive solution must be chemically identical; (3) growth in living things leads to the production of more living things, while growth in inorganic nature never does. LeConte succinctly expresses this distinction in the following sentence: "It (organic life) manufactures materials like itself out of materials wholly different from itself and then uses the product for growth."

7. *The Awareness of Living Protoplasm.*—All forms of living protoplasm respond more or less to changes in temperature, like winter and summer. The habit which certain trees have of shedding their leaves is a well-known example. The small organisms react to the stimuli of their environment in a rather definite manner, as the reactions of the paramecium indicated. In the higher animals a definite specialization in the form of the nervous system occurs which takes on the work of receiving and transmitting stimuli, and, with the assistance of the muscles, producing a definite coördination (irritability, conductivity and coördination) (page 94).

8. *Maintenance of Life.*—Not all young plants and animals grow to maturity nor do all adults continue to live to old age. Death is one of the most obvious facts connected with life and occurs at all ages. The keeping of the organism alive is a process distinct from growth, for it continues long after growth ceases. The technical term of metabolism (defined on page 47) is used to describe the intricate and complex changes that take place in living protoplasm as the individual organism passes from the embryo through youth to maturity and old age. Associated with the maintenance of living protoplasm is the production of those bodies to which the name of ferment or enzyme has been given.

The Fate of Dead Organisms.—Ultimately all forms of life die, and yet the surface of the earth is not cumbered with them as would be the case if they remained intact after death. The group of organisms included under the heading Ferment Organisms, particularly the saprophytes, begins to tear down the substance of these dead bodies, and this continues through a longer or shorter time until there exist a number of free chemical elements in the place of the organism. The substance of the dead organism has been returned to Nature and the chemical elements have been released and set free. This fact when taken with the above distinctions of living protoplasm constitute one of the important characteristics of life. None of them have been destroyed, and all of them are available to be used by some form of life. It is thus seen that the elements that enter into the living protoplasm pass through a fairly regular cycle. No one can tell how many times the oxygen that we are breathing has been a part of other living things nor for how long a time. All that we know is that it is useful to us. It does not matter how often nor how long an element is used so far as its usefulness to future living things is concerned, provided it is properly combined so that the plant or the animal protoplasm of perhaps a thousand years hence can utilize

it. We may feel then that there will always be plenty of the necessary chemical elements to support life, because living matter does not destroy them and cannot exhaust them, but simply holds them in the living relation for a longer or shorter period.

Life or living protoplasm is thus seen to be composed of certain limited chemical elements having a characteristic physical appearance. The biological properties are distinctive for matter in the living condition and are not found united in any of the inorganic bodies. Any new creation of life that may be announced from time to time must have all of these characteristics if it is to be identified with the life which now exists. With the great amount of specialization that is being carried on it is pertinent to urge that life should be studied as a whole and not as so many parts, for it is really the whole life that determines the several parts and processes. It is also desirable to urge that for the biologists LIFE is the fundamental reality and not the physics or chemistry of it.

REFERENCES.

- BUTSCHLI, O.: Investigations on Microscopic Forms and on Protoplasm.
HALDANE, J. S.: The New Physiology, Science, 1916, p. 619.
OSBORNE, H. F.: The Origin and Evolution of Life.
SPALLANGANI, FOSTER: Lectures on Physiology.
TYNDALL: Floating Matter of the Air.
VALLERY-RADOT: Life of Pasteur.
LOEB: Natural Death and the Duration of Life, Scientific Monthly, 1919, vi, 578.

PART III.

PLANT AND ANIMAL TYPES ILLUSTRATING BIOLOGICAL PRINCIPLES.

CHAPTER XII.

SOME LOWER PLANT TYPES.

Thallophytes.—Probably the most important thing about a plant is the way that it gets its food. The normal plant, whether it be simple or complex, is one that can gain its food from Nature. It is not a dependent organism. To this fundamental conception in regard to the nature of a plant should be added another, namely, that there has been an evolution in plants along divergent lines, resulting in the formation of plant groups, in which the genetic relations are complicated. In this process of evolution, however, some of the structural characters of the simple plants are to be found in the higher, although greatly modified.

In the thallophyte phylum are placed the simplest forms of plants. The body is a thallus and there is no root, stem or leaf in the usual sense. The cells of the plant are similar and tissues are absent except as noted below. In some members of this group root-like processes, known as holdfasts, are developed. Many of these plants are fragile, having the cells united into linear series, while others are like the brown kelp, tough sea-weeds, many feet in length.

As the classification indicates the thallophytes are composed of many normal chlorophyll-bearing plants, the algæ, and the divergent and dependent group of fungi, many of which show definite algal affinities. The fungi live as parasites, saprophytes and symbionts, and their relations to disease in plants and animals is so important that a separate course is necessary to present even the general facts of disease in fruits, in grains, in trees, in domestic animals and in man.

The life cycle of this group is relatively simple as compared with the remaining phyla of plants, and this serves as their chief distinguishing character rather than the nature of the thallus. For some of the higher plants have thalloid bodies, and some algæ have a stem-like and leaf-like structure, as complicated as that of mosses, and a well-defined system of tissues. This group, then, is especially interesting because it shows the beginning of tissue differentiation and the origin and earliest expression of sex and sex organs.

CHLOROPHYCEÆ, THE GREEN ALGÆ.

This is the largest class of the algæ, containing more than 8000 species. They are found in both salt and fresh water as well as on land. Of the simpler plants, several members of this class are among the most common. The familiar "pond scum" or "frog's spittle" in the ponds and slow-running streams, as well as the green covering on moist surfaces of the earth, in pots, etc., called "green felt," are two of these plants that are first studied. The former is some form of *spirogyra* and the latter *vaucheria*.

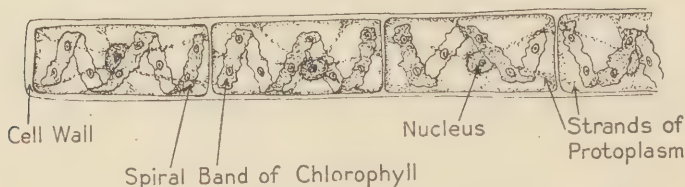


FIG. 87.—*Spirogyra* as the cells appear except when conjugating.

Spirogyra.—"Pond scum" consists of many long, silky threads. Each thread is a complete plant of several cells attached end to end. The green color varies. Each cell of *spirogyra* is large and cylindrical in shape. In each cell there are one or more spirally arranged bands containing chlorophyll; these are the chromatophores or chloroplasts; their number and their manner of coiling depend upon the species. The cytoplasm is distributed in the cell as a thin layer next to the cell wall. Fine threads of cytoplasm extend from all sides to the nucleus. The center of the cell is occupied by sap. In the chloroplasts are several pyrenoids which are the special centers where the starch is manufactured (p. 100). *Spirogyra* is composed of nearly 98 per cent. water, and yet the vital processes of the plant are adequate to enable it to manufacture food. The masses of

spirogyra are frequently full of bubbles of oxygen that are given off in this vital process.

Spirogyra reproduces by normal cell division, and the new cell wall forms at right angles to the length of the filament. Such divisions cause the filament to increase in length. This form of cell division takes place very rapidly. The second form of reproduction is important because it illustrates an early stage in the development of the sexual method. The cells of two plants that lie near together form connecting bridges (Fig. 88, *A*), which are tubular outgrowths that eventually furnish a continuous passage between the connecting cells. The protoplasmic contents of one cell flow into the other and the two masses unite into a single body, which has become much

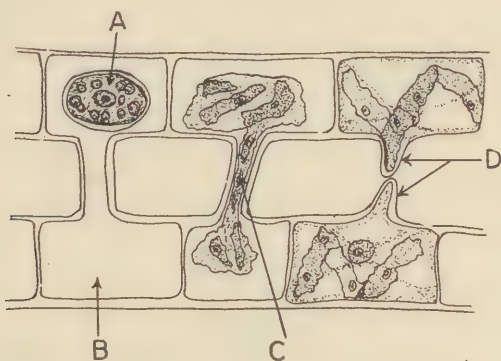


FIG. 88.—*Spirogyra* conjugating. *A*, zygospore; *B*, empty cell; *C*, protoplasm flowing from one cell into another; *D*, each cell is forming an outgrowth which unites to form a passageway between the two cells.

reduced in size. A thick cell wall is secreted around this body, which is termed a spore. In view of the fact that the masses were formed by the fusion of similar cells the spore is called a zygospore (a yoked spore). The two protoplasmic masses that fused are called gametes. "Cells that unite to form sex spores are called gametes; hence a zygospore is a sexual spore that is formed by the union or conjugation of similar cells." As the parent plants decay the zygospores escape. A period of rest follows, caused by a drought or winter, after which each one begins to grow into a new spirogyra. The formation of this reproductive spore is of obvious advantage.

Vaucheria.—This is the common "green felt" which is usually found growing on the soil, although it may be found in the water.

The filaments are coarse, much longer than spirogyra, and branching. Plants taken from the soil usually penetrate it slightly. The youngest branches are the greenest. The whole filament consists of a single cell with numerous nuclei scattered throughout its length. This arrangement may have arisen through the failure of the dividing cell to form walls. Such a condition is termed a coenocyte or syncytium. The cytoplasm of vaucheria contains numerous chloroplasts, which indicates that it has the power to manufacture an abundance of food.

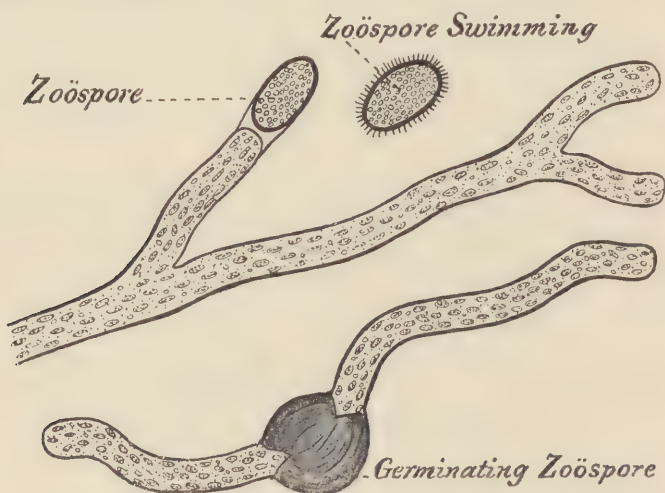


FIG. 89.—Vaucheria—asexual reproduction.

Asexual reproduction accidentally takes place when the old end of the filament dies, and as it decays sets free the branches which now become separate plants. Asexual reproduction normally begins by the formation of a cross-wall in one of the branches. The isolated protoplasm becomes transformed into a large zoospore (Fig. 89). This body escapes into the water and swims about for a time, then grows into a new vaucheria. The zoospore is made up of many cells, although it gives rise to but one plant. Sexual reproduction occurs through the formation of special short branches on the side of the plant (Fig. 90). On this branch one or two large oval masses appear with a beak-like process. The terminal branch in the figure is long and coiled with a terminal cell cut off from the rest of the branch. In this terminal cell many small cells are formed which escape into the water. By means of long cilia they are able to swim about. One of these cells enters the oval mass. After the union of the two

gametes, a thick wall is formed about the cell which is called an oöspore; after a period of rest it grows into a new plant. The only difference between this process in *Vaucheria* and the conjugation in *spirogyra* is in the unequal size of the uniting gametes. The large oval mass that receives the small free-swimming gamete is now called an egg or oöspore, while the small free-swimming gamete is a sperm. *The union of the sperm and egg is fertilization.* The special cell which produces the sperms is termed the antheridium, while the cell that produces the egg is the oögonium.

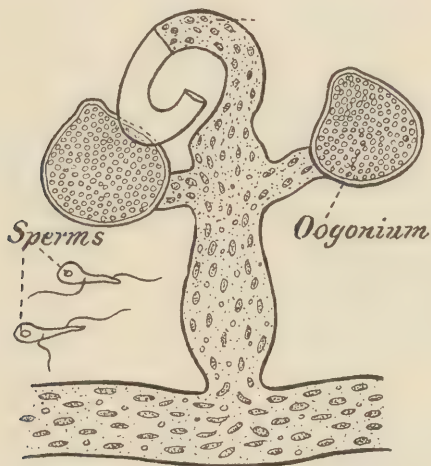


FIG. 90.—*Vaucheria*—sexual reproduction.

PHYCOMYCETES, THE ALGÆ FUNGI.

The general subphylum of fungi includes one of the largest groups of plants: there are more than 64,000 known species.

The general habitat of this group is well expressed by Underwood as follows: "Whether we are aware of their existence or not, there are in the world about us a vast array of more or less inconspicuous organisms that are known to botanists under the name of fungi. These differ among themselves in size and structure far more widely than do a violet and an oak, and many of them at first sight would seem to bear so little resemblance to one another as to possess no real relationship. Many of them are known more or less popularly under common names such as moulds, mildews, mushrooms, toadstools, puff-balls, rusts, smuts, leaf spots and blights, each popular

name indicating a more or less indefinite group of plants more or less closely related to one another. They grow in every conceivable place where organic matter can be found which will serve as their food, and a moderate degree of heat and moisture are present to furnish the necessary conditions of growth. Decaying fruit or vegetables, oily bones, old musty shoes, wet paper, the dead stems of herbaceous and woody plants, the dead and dying branches of trees, standing stumps and tree trunks and fallen logs all furnish the matrix in which fungi of various sorts, a few conspicuous, many more inconspicuous, thrive and multiply. With all their differences fungi agree in two characters: (1) No chlorophyll. (2) They reproduce by spores. In the many different substances enumerated above, all are the product of some form of organic activity. This permits the habitat of fungi to be subdivided into (1) those that live upon dead organic matter and are called saprophytes, and (2) those that subsist upon living organisms and are known as parasites."

The algæ fungi, as the name suggests, are fungi which are similar to algæ. The well-known bread mould illustrates some of these similarities.

The Bread Mould is a common form of one of the simple moulds that grows in our homes upon bread, fruit and other suitable substances. It consists of a tangled mass of thread-like structures, which is the main working body of the plant. The name mycelium is given to the interwoven mass, which may become quite compact in older growths. The individual threads are called hyphæ. Some of the hyphæ send out special threads which are known as rhizoids and penetrate the nutrient material. The bread mould derives its nourishment directly from the nutrient substances upon and in which it is growing. We may believe that the foods found in the bread are utilized through the production of certain enzymes by the hyphæ. The reason for believing that this is the method is because *Aspergillus niger*, a mould, has the reputation of forming a large number of enzymes; and *Pencillium camemberti* (the chief organic agent in ripening Camembert cheese), according to Dox, produces the following enzymes: erepsin, dulclase, aminase, lipase, emulsion, amylase, inulase, raffinase, invertase, maltase and lactase. The formation of the mycelium takes place by the asexual or vegetative method of reproduction. After a time a number of upright stalks are produced from the mycelium and are called sporangio-phores (sporangium bearers). The tip of each upright branch produces a globular sporangium which is full of spores. The walls

of the sporangia burst and the dust (spores) is scattered by air currents.

When the bread mould reproduces by the sexual process, which it does rarely in nature, the process is interesting because it is so similar to *spirogyra*. The free ends of two hyphæ come in contact (Fig. 92) and end cells are cut off. These two end cells enlarge and eventually unite to form a single spore with a dark heavy wall (Fig. 92). The two cells which contribute to the formation of this spore are similar, and so the resulting body is a zygospore.

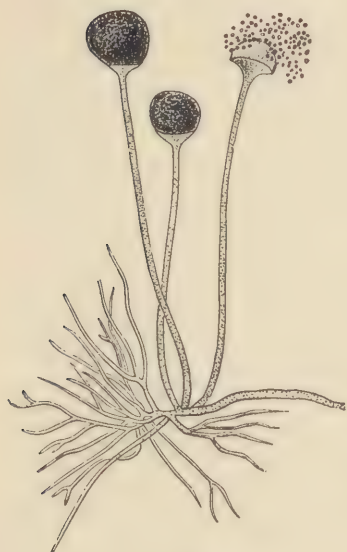


FIG. 91.—Bread mould.

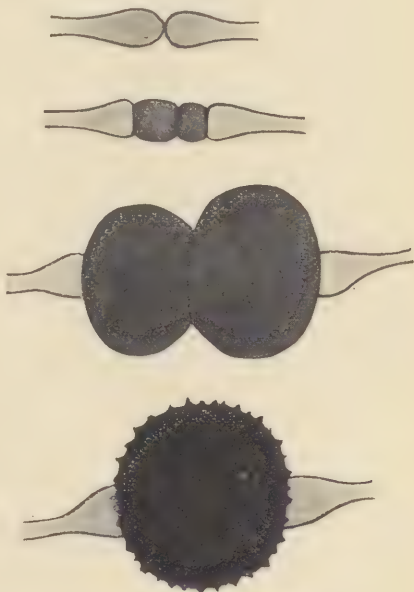


FIG. 92.—*Mucor* spore formation.

Water Moulds.—There is one very common water mould which lives upon dead insects, fish and other animals. This mould has the interesting habit of thriving either on a dead fish or one that is alive, readily assuming either the saprophytic or the parasitic habit. At times it becomes a serious pest in fish culture. A culture of water mould (*saprolegnia*) is usually secured by simply dropping a dead fly found on the floor or window sill into a dish of water. There is soon formed a whitish mass of hyphæ growing out in all directions from the insect. The hyphæ on the body of the insect digest such parts as may serve as food, and it is in this way that they are effective

agents in destroying dead animals in the water. The water mould reproduces by the asexual and sexual methods. The water and bread moulds serve to illustrate a type of plant life that has its food already made; they are plants related to certain green plants and they differ from them chiefly in the absence of chlorophyll. This suggests that the habit of utilizing ready-made food is really an acquired habit. More or less closely related to these common moulds are the mildews, rusts and many others less well known.

CHAPTER XIII.

SPERMATOPHYTA—TRILLIUM GRANDIFLORUM.

Spermatophytes.—The division spermatophyta (meaning seed plants) contains not only the groups frequently called “flowering plants,” but also other groups which do not have flowers, for the reproductive organs are borne in cones or clusters which are not at all showy, but rather inconspicuous (see Appendix). The spermatophytes have also been called phanerogams (meaning evident marriage) to distinguish them from all the lower groups of plants which are called cryptogams (meaning hidden marriage). However, this separation was made before the sexual processes of the lower plants were understood, for, as a matter of fact, they are much more evident than the complicated ones in the seed plants. The seed is a more significant structure in the group than the flower, so the name spermatophyte has in recent years come into general favor. The seed plant, like the fern, is a sporophyte. There is a gametophyte generation in the life history, which is, however, so much reduced in structure that it can only be understood by a careful study of the reproductive processes in seed formation.

The Seed.—“The importance of the seed in the development of plant and also of animal life can hardly be exaggerated. For the plant it furnishes one of the surest means of reproduction not only because of protective structures, means of dispersal, long vitality, etc., but also because the embryo plant is carried so far forward in its development that it is able to take root and establish itself at once. And further to aid the embryo, the seed is a storage organ of the most condensed forms of food material found in plants. In this respect, also, the seed has proved a most important influence in shaping the habits and in a large measure the evolution of some forms of animal life; for the highest groups of animals live to a very great extent directly or indirectly upon food stored in seeds and certain fruits, finding there some of the richest and most nutritious proteid and carbohydrate foods.” (Bergen and Davis.)

The pollen grain of seed plants corresponds to the microspores of pteridophytes and produces a male gametophyte which bears sperm

cells. Similarly, within the ovule of the seed plant occurs a cell which corresponds to the large spore (megaspore) of pteridophytes and which produces the embryo sac in which the egg is formed. In order that fertilization may take place, the pollen grain produces an outgrowth or pollen tube which penetrates the tissues surrounding the egg and carries the sperm cells to the egg.

The spermatophyta have the most perfect expression of root, stem and leaf found in any plants. It is but a short process to perfect the formation of the seed already anticipated, and so the members of this group have become differentiated in solving the life-cycle problem, with the result that they have expanded into a multitude of forms following two lines of evolution, one the monocotyledons, in which the cat-tail flag may be thought of as the lowest and the orchids as the highest; and the dicotyledons, in which a similar primitive and recent display is represented by such plants as lizard's tail and the crowning group of composites.

Trilliums.—The common trilliums belong to the family of plants known as the Liliaceæ, which includes some 2500 species that are widely distributed and extensively cultivated. Among the cultivated species that are familiar are the hyacinths, lilies, tulips, lily of the valley. Asparagus and onions are lilies cultivated for food and the aloes, colchicum and others are used in medicines.

There are several species of trilliums in the United States, of which the wake robin (*Trillium grandiflorum*) is the commonest. Its natural habitat is in or near the woods, where it is frequently found with the painted trillium. Fig. 93 gives a good idea of the habitat of the trilliums.

The entire plant consists of a thick, fleshy, underground stem or rhizome from which arise numerous strong, wrinkled roots, and a leafy flowering stem bearing leaves and the flower. The rhizome lives on for a number of years and so is termed perennial. It is marked by ridges and scars which indicate something as to its age, since each scar indicates where a single flowering stem was attached.

The new leaf stalk arises from the growing end each year. The leaf stem normally bears a whorl of three sessile leaves near the flower. From the center of this whorl arises the flower stalk bearing a flower at its summit (Fig. 94).

The flower is the most conspicuous feature of the higher plants. It has passed through many evolutionary stages before we come to the highly developed flower of the trillium. The parts of this flower

are the calyx, the corolla, the stamens and pistil. The calyx consists of a whorl of three-pointed, green, leaf-like structures. Each individual part is called a sepal. The calyx is thus seen to be made up of three sepals, which are easily recognized as similar to the leaves. While the corolla is made up of structures similar to the sepals, they are wider and white in color. Each member is termed a petal. Within these two whorls of leaf-like structures are found two whorls



FIG. 93.—Painted trillium.

of much smaller parts, the stamens. Each stamen consists of a stalk or filament bearing an enlarged part called the anther. Each anther consists of four sacs which fuse into two as the contents become mature (Fig. 96, C). These sacs contain a quantity of yellowish spores which are the pollen grains. In the center of the flower is the stout, angular pistil which terminates in three long, slender, curved points (Fig. 96, A). On the inner surface of each of these

points is a roughened area that is sticky; these are the stigmas of the pistil. The base of the pistil contains a three-lobed chamber (Fig. 96, *B*), in which are many ovules:



FIG. 94.—*Trillium grandiflorum*.

Study of the development of the stamens of flowers has shown that they are modified leaves; similarly, the pistil in trillium is composed of a group of three modified leaves called carpels.

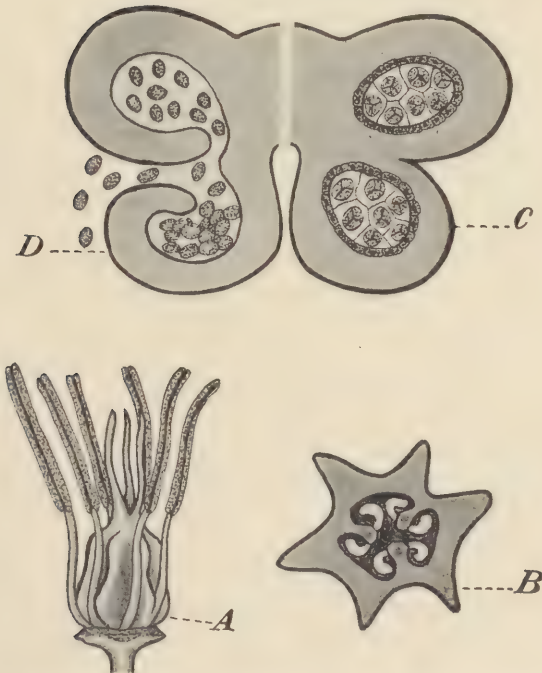
FIG. 95.—*Trillium grandiflorum*.

FIG. 96.—*A*, stamen and pistil of trillium; *B*, cross-section of the ovary, showing ovules; *C* and *D*, cross-section of anther; *C*, young anther, showing formation of pollen grains; *D*, mature anther.

In trillium the sepals and petals are very much like leaves, but one does not see the superficial resemblances as readily in the stamens and pistil. The development of these two organs, however, leaves no doubt as to their origin. The writer found striking confirmation of this theory in nature. The trillium shown in Fig. 95 showed basal leaves with long petioles, and sepals and petals both green and similar to the leaves. But most significant of all was the condition of the stamens and pistil. Each of these organs of the flower was green in color, all were supported on stalks similar to the leaf petioles, while some of the stamens were broader than the normal stamens.

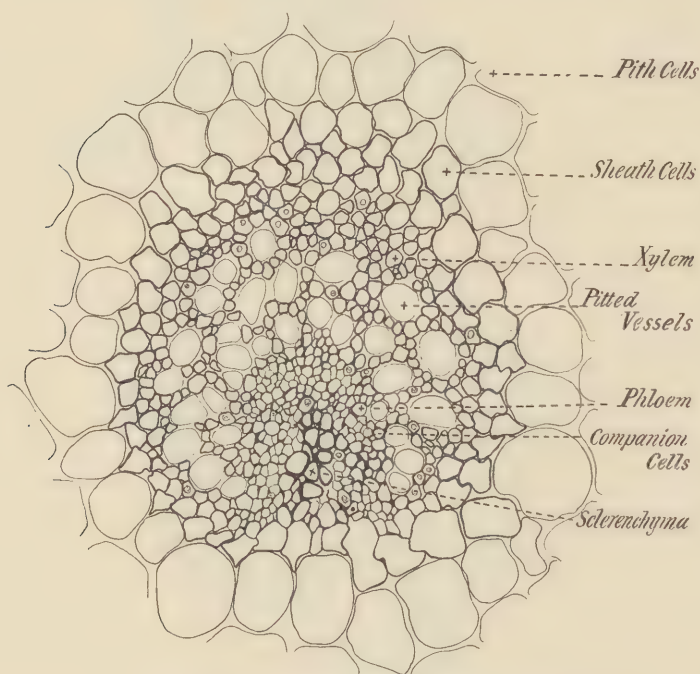


FIG. 97.—Fibrovascular bundle of trillium.

The structure of the flower stem shows that there is a definite number of tissues, each with its own work to do. On the outside there is an epidermis of one layer of cells which is protective; inside of this are one or two layers of a thick-walled tissue also protective in function. A thin-walled tissue, the pith, makes up the bulk of the whole stem, and scattered in the pith are numerous fibrovascular bundles. The detailed structure of a fibrovascular bundle in trillium is shown in Fig. 97. In the leaves the veins are the fibrovascular

bundles and the epidermis tissue becomes differentiated into an upper and a lower epidermis (Fig. 98). The under surface of the leaf is furnished with stomata which regulate the outgo of moisture from the leaf. The interior of the leaf is composed of cells which contain many chloroplasts. In the chlorophyll bodies the carbohydrate food of the plant is made (see page 100). While carbon forms nearly one-half of the dry weight of plants, yet all of this carbon is derived solely from the carbon dioxide in the air. It is estimated that a square meter of leaf surface can draw all of the carbon dioxide from 2500 liters of air in one hour. This furnishes sufficient carbon

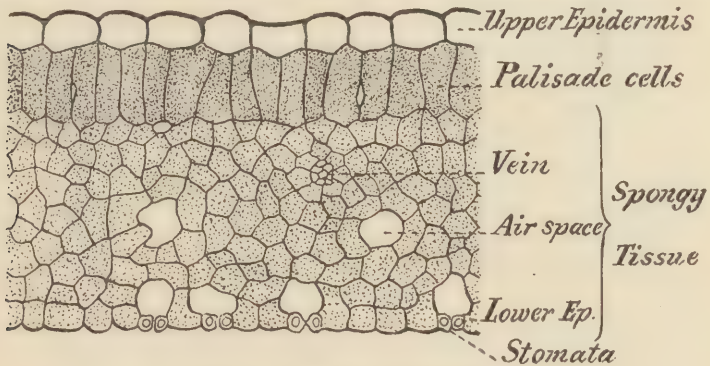


FIG. 98.—Section through lily leaf.

for the construction of one gram of starch. The food made in the leaf is transferred to all parts of the plant. The phloem cells in the fibrovascular bundle carry the food while the water travels in the xylem strands. All excess of food is stored in the underground stem. As the food circulates through the plant it is absorbed by the cells and utilized in the life processes of the plant. The principles of digestion are the same as for the frog. A plant protein is non-diffusible and must be rendered diffusible. Digestive enzymes prepare the plant food for the cells.

The young flowers of trillium begin their development in June or July and by autumn are well formed, though they remain protected by the sheathing bud during the winter and blossom in the early spring. The tips of the plants appear above the ground about the middle of April and the flowers are usually in full display by the first of May in central New York. Since the structures and processes concerned in the reproduction of flowering plants by seeds are essentially the same for all species, a general account of these structures and processes is given here.

The pollen grains are formed in the anther while the flower bud is still very small—in trillium at about the time that the shoots come above the ground. The pollen grains are single cells, usually with thick, roughened walls. They correspond to the microspores of the

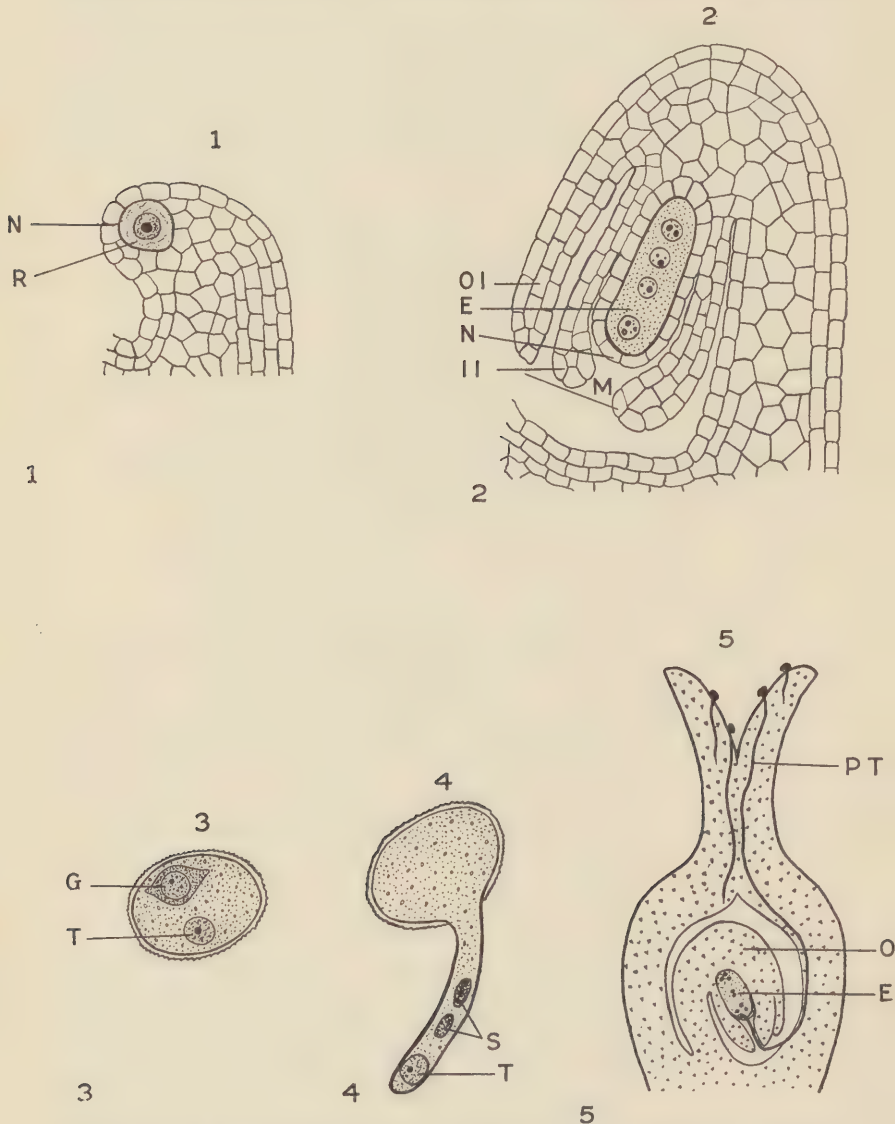


FIG. 99.—1, young ovule of *Lilium*. N, nucellus; R, embryo sac mother cell. 2, older ovule; E, embryo sac; II, inner integument; OI, outer integument; M, micropyle. 3, pollen grain of *Lilium*; G, generative cell; T, tube nucleus. 4, growth of the pollen tube; S, sperm cells. 5, diagram of pistil, showing the course of the pollen tube; O, ovule; PT, pollen tube.

pteridophytes. As the flower develops the nucleus of each pollen grain divides, forming two cells, known respectively as the generative cell and the pollen tube cell (Fig. 99, 3); this is the condition of the pollen in the mature flower.

The ovule first appears as a projection on the inner wall of the ovary. Within the ovule is a large cell which may be called the embryo sac mother cell and is the equivalent of the megaspore of

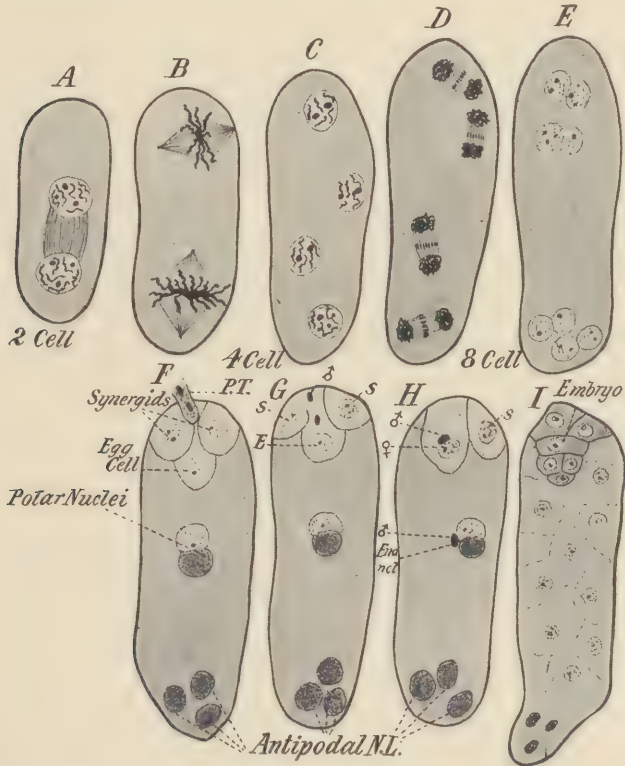


FIG. 100.—Development of the embryo sac of seed plants. P.T., pollen tube. (Redrawn from Coulter.)

the pteridophyta. This cell is contained within the nucellus; as the ovule develops, two protective layers, the integuments, develop above the nucellus, but never entirely enclose it. The small opening that is left is the micropyle (Fig. 99, 1, 2).

As the flower grows the ovule enlarges and the nucleus of the embryo sac mother cell (Fig. 99, R) divides. The two daughter nuclei then divide simultaneously, producing four free nuclei (Fig. 100, C); another simultaneous division occurs, producing eight nuclei,

which collect in two groups of four each in the ends of the greatly enlarged embryo sac (Fig. 100, *D, E*). Delicate membranes occur about three of the nuclei at the end of the embryo sac toward the micropyle, forming a group of three naked cells known as the egg apparatus. The two lateral cells are the synergids; this term means "helpers," and indicates that they are supposed to assist in fertilization. The cell between the synergids is the egg; it is often somewhat larger than the synergids. Three of the nuclei at the opposite or antipodal end of the embryo sac remain for a time unchanged or in some instances organize cells by the formation of delicate walls; in any case they eventually degenerate. The remaining two nuclei, one at either end of the embryo sac, and known as polar nuclei (Fig. 100, *F, G, H*), move through the cytoplasm toward the center of the sac and come to lie in contact with each other. This entire structure of eight cells, one of which is an egg, is a sexual phase of the life history of the plant, the female gametophyte. It reaches this mature condition in the fully opened flower.

Pollenization is the transfer of pollen from the anther to the stigma of the pistil. It may be brought about by many agencies, such as wind, insects and even water, as in the case of some plants with submerged flowers. Of these agencies, the wind, is most important in the simple flowering plants, such as willows, poplars, etc.; but in the great majority of species pollenization is effected by insects which visit the flower to secure nectar or other food furnished by flowers. In securing this food the insect brushes against the anther and some of the pollen adheres to its body. In the course of the normal feeding of these insects some of this pollen will come in contact with the stigma of the same flower or of another of the same species and pollenization will be accomplished.

When the pollen grain has been transferred to the stigma it begins at once to grow, forming a tube which digests its way through the style of the pistil (Fig. 99, *5*). The nuclei of the pollen grain pass down into the tube and the generative cell soon divides into two sperm cells (Fig. 99, *4 S*). This structure of three cells is the other sexual phase of the life history, the male gametophyte. The tube continues its growth through the tissues of the pistil until it reaches the vicinity of the ovule, where it turns aside and enters the micropyle. A passage is digested through the nucellus and the two sperm cells are discharged into the sac. One of these fuses at once with the egg cell (Fig. 100, *H*); this is fertilization, the sexual process involved in reproduction in seed plants, and is not to be confused with pollenization, which is not sexual.

The other sperm cell moves through the cytoplasm to the center of the sac, where it comes in contact with the two polar nuclei (Fig. 100, *H*). The three nuclei then fuse, forming the primary endosperm nucleus, and the process is called triple fusion. This nucleus soon divides and repeated divisions of the daughter nuclei follow, producing an extensive thin-walled tissue, the endosperm, which fills the entire embryo sac. This is a nutritive tissue and supplies food to the embryo.

The fertilized egg soon divides, forming a mass of several cells, the embryo (Fig. 100, *I*). The further growth of the embryo carries it deep into the endosperm, from which it absorbs food. At the same time the integuments about the embryo sac harden and become the seed coats or testa. The embryo now stops growing and remains in a dormant condition and the seed is mature. When the seed is placed in favorable conditions of heat and moisture, water is absorbed and the embryo resumes growth; this is the germination of the seed and results in the formation of a new plant.

It is to be noted that the life history of a seed plant shows the same alternation of sexual and sexless phases that is seen in the lower groups. The ordinary flowering plant of which the trillium is an example is the sexless or sporophyte phase, and the nucleus of each cell contains twelve chromosomes. This plant produces microspores, or pollen grains, and megaspores, or embryo sac mother cells; in the nuclear divisions which produce these cells, the chromosome number is reduced to half its original number, that is, six in the case of the trillium. The pollen grains produce one of the sexual phases of the life history, the male gametophyte which forms sperms; the embryo sac mother cell produces the other sexual phase, the female gametophyte which bears an egg. Fertilization occurs by the fusion of a sperm cell with the egg; thus the nucleus of the fertilized egg contains twelve chromosomes, six of which have been contributed by the sperm and six by the egg. This fertilized egg develops into the embryo of the seed, which, upon germination, becomes the mature sporophyte or sexless phase of the life history with its characteristic number of chromosomes.

REFERENCES.

ATKINSON, G. F.: Reducing Division of the Chromosomes in *Trillium Grandiflorum* during Sporogenesis, *Bot. Gaz.*, 1899, xxviii, 10.

ERNEST, A.: Chromosomenreduction, Entwicklung des Embryosacks und Befruchtung bei *Paris quadrifolia* L. und *Trillium grandiflorum* Salisb. *Flora oder Allgem. Bot. Zeitung*, 1902.

CHAPTER XIV.

SOME INTERMEDIATE TYPES AND HYDRA—AN ANIMAL MADE UP OF TISSUES ONLY.

Intermediate Types.—In all of the study of animals and plants no one has ever observed one of them coming into being except through the direct influence of a previous living animal or plant. This is now regarded as the biogenetic law (page 112). Whatever may have been the primal origin of life the present animals and plants are genetically related. This fact makes it necessary to explain the possible origin of organisms consisting of more than one cell or the multicellular forms of life.

This problem is not fully solved, but a fair start has been made through the study of intermediate types which serves as an introduction to Hydra, an animal made up of tissues.

There are no sharp limits to the several phyla, so that there are a number of animals that fall between certain phyla or are grouped in an appendix to a given phylum. Some of these intermediate forms are interesting because they show how a higher form may have come into existence. This becomes a problem of great interest when the transition between *protozoa* and the next higher form, the many-celled *metazoa*, is made. In the unicellular animals the whole life is carried on within the limits of a single cell. Differentiation of work or structure is lacking, for the whole cell participates in the digestion of food, in metabolism and in reproduction.

The *Colonial vorticellidæ* consist of a number of like individuals arranged in a tree-like fashion (Fig. 69). Each individual is independent in all vegetative and reproductive functions. The cells are similar in size. These animals are termed colonial protozoa, but there is the beginning of cohesion of the cells.

Gonium is a sixteen-cell organism in which the cells are all alike, but united into one common body. Each cell eats, breathes, reproduces, etc. The cells are held together by their own gelatinous secretion. During the reproductive period the cells separate and act like unicellular organisms. This organism shows the first step in the union of cells, although it is not permanent (Fig. 101).

In gonium the reproductive cells are all alike but in endorina two kinds of conjugating cells are produced at intervals, the megagametes and the microgametes. Each of these cells is set free in the water, the small cells swimming about until they come in contact with the large cells, into which they penetrate. These two cells constitute a zygote, from which develops a new endorina.

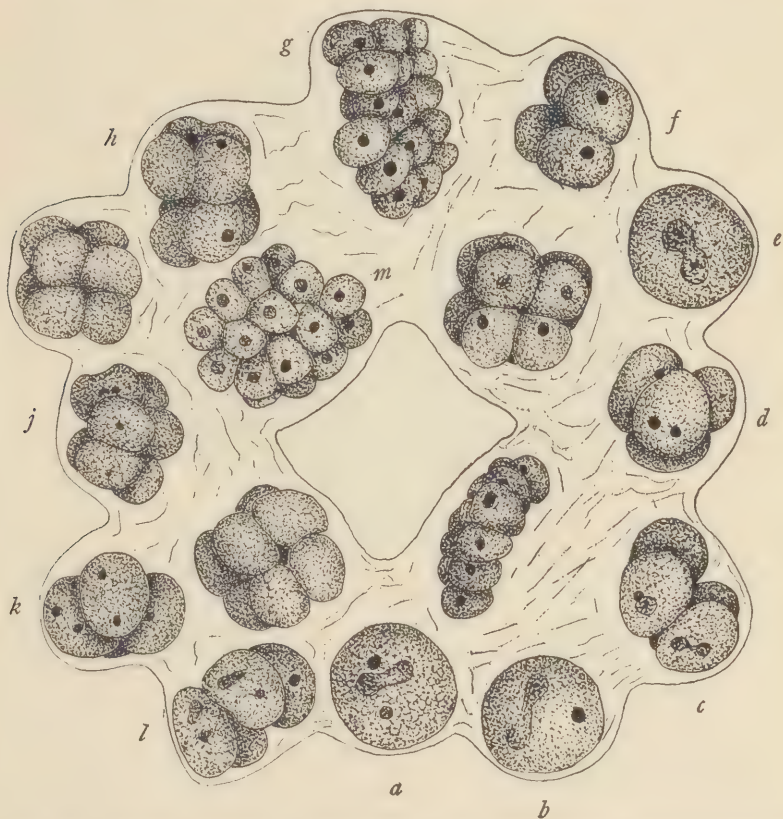


FIG. 101.—*Gonium pectorale* in reproduction. Each of the sixteen cells of the colony is dividing to form a daughter colony of sixteen cells. (After Calkins.)

Volvox is an organism consisting of a number of cells varying with the species from five hundred to fifteen thousand. The cells are arranged in the form of a hollow sphere and are separated from one another by a jelly-like substance through which pass fine protoplasmic threads. The cells are all much alike until the reproductive period, when certain cells become specialized into eggs or

sperms. During the growth of these reproductive cells they are nourished by the other cells in volvox, which is a marked step in advance over pandarina and endorina. Before one can recognize that there has really been a differentiation of cells the process must have been preceded by the formation of cells of different sizes.

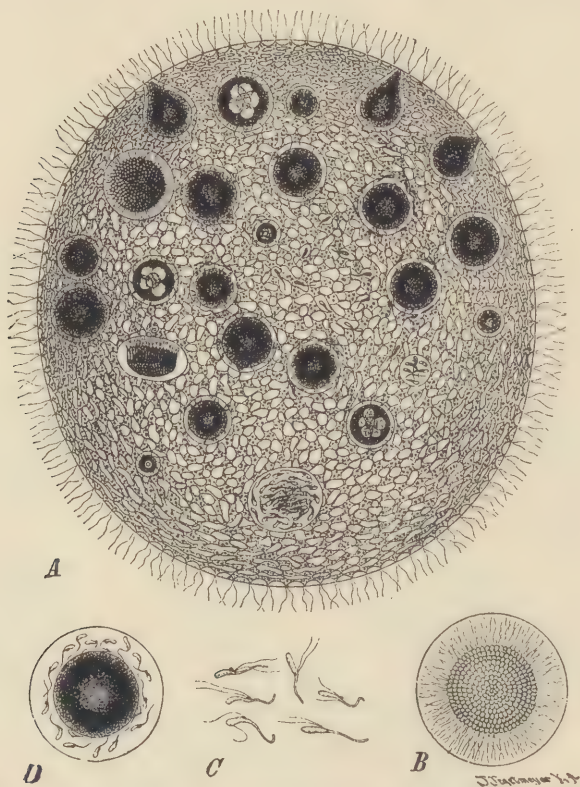


FIG. 102.—*Volvox globator*. A, colony containing various stages of development of ova and sperms ($\times 165$); B, bundle of sperms formed from division of a single cell ($\times 530$); C, sperms ($\times 530$); D, egg cell surrounded by sperms in the mucilaginous membrane ($\times 250$). (From F. Cohen.)

This means that unequal cell division is an accompaniment of differentiation. After the cells of volvox have produced and nourished germ cells until they can in turn produce new volvoxes they die.

In these examples given, and many more might be included, there is an obvious transition from the simple to the complex state. The cells tend to become more divergent in structure with an accom-

panying unification. "For efficient advance in the life scale integration and differentiation must go hand in hand." The higher animals are those in which integration and differentiation have been carried the furthest.

These intermediate organisms reveal two important biological principles, *the first steps in the physiological division of labor and sex dimorphism*. The first has already become familiar. Sex dimorphism considers the origin and significance of sex, dealing particularly with the distinction between ovum and sperm. In the following study of hydra the complete differentiation has taken place and sexual reproduction has become established. The significance of sex dimorphism in heredity and variation is described in Part V.

Kinds.—There are two common species of hydra that are abundant in fresh-water streams and ponds. Due to the presence of innumerable chloroplastic corpuscles one is bright green, which gives it the name *Hydra viridis*. The other species is of a light brown color, due to the presence of yellowish corpuscles, and is known as *Hydra fusca*. *Hydra fusca* is much larger, otherwise the two are very similar. Hydra can easily be seen in an aquarium jar attached to the side nearest the window. They vary in length from 2 to 20 mm.; this is largely due to the fact that the body is capable of great expansion and contraction. The hydra represents a small group of animals in which the absence of well-defined organs made up of tissues such as are found in the frog is a conspicuous characteristic. Nevertheless they are able to do all of the essential things that the frog does to maintain existence. They have been studied for many years as representing the simplest of the many-celled animals.

Morphology.—In general shape the body is a cylindrical sac attached at one end, which is the foot or basal disk (Fig. 103). The foot is not permanently fixed but adheres partly through the action of adhesive gland cells and partly by forming a vacuum. The mouth is somewhat star-shaped and is on the distal end, situated on the top of a conical elevation, the hypostome. Tentacles arise from the body at the junction of the body wall and hypostome and vary in number on *Hydra viridis* from four to twelve and on *Hydra fusca* from six to ten. They are capable of great expansion, as they move independently about searching for food and capturing it.

Food.—The hydra is more or less carnivorous, sometimes devouring algæ, etc., but feeding especially on the small water fleas which are seized by the tentacles and drawn into the mouth. The mouth

opens and the daphnid is slowly swallowed and passed into the digestive cavity. The indigestible parts are afterward expelled by way of the mouth. Within the body of the hydra there is a single cavity which communicates directly with the hollow tentacles. This cavity serves for digestion and circulatory work, and hence is termed the gastrovascular cavity or enteron.

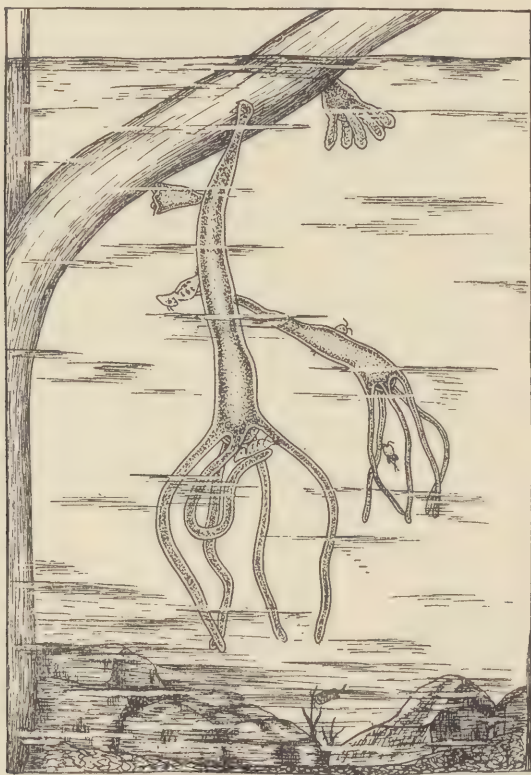


FIG. 103.—The brown hydra of Lake Clear, N. Y. During the summer this hydra becomes a bright red color. It feeds upon daphnia and cyclops as shown in figure. The small specimen attached to the leaf is in the contracted condition. Note the two buds on the body of the large expanded hydra.

Structure.—The body of the hydra is composed of two layers of tissue: the outer, the ectoderm, and the inner, the endoderm (Fig. 104). These two layers are separated by a jelly-like, non-cellular layer, the mesoglea, which appears as a line when viewed in a microscopic section. The ectoderm has no connection with the food

cavity, so that these cells are nourished only as food is absorbed, first passing through the endoderm and mesoglea. The outer layer of ectoderm serves to protect the hydra and also to act as a generalized sense organ. The protective cells in the ectoderm are the nematocysts, which are described below. There are no well-defined sense organs such as ears, eyes, etc., yet the hydra responds

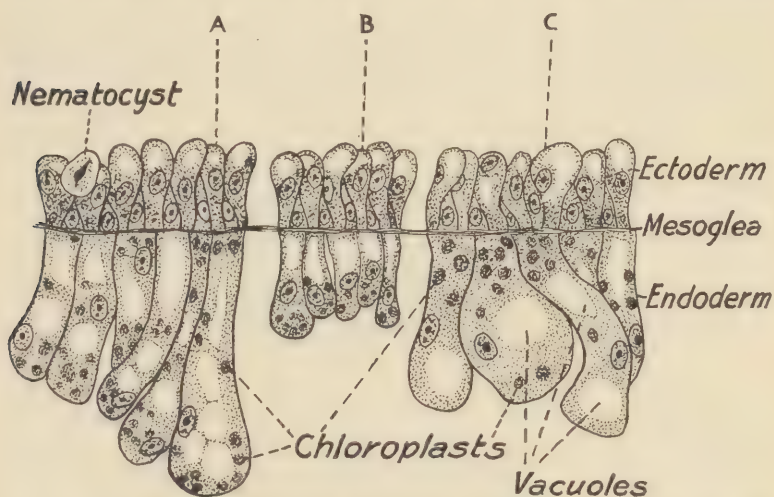


FIG. 104.—Section of the body wall of red-brown hydra taken from Little Lake Clear, February, 1917. A, region of esophagus; B, middle body region; C, taken about 1 cm. above the region of the foot.

to different degrees of light, to jars, and touch. There are, however, some specialized cells in the ectoderm which respond to stimuli and are in connection with an indefinite plexus-like layer of cells to which the name nervous system has recently been given. The endoderm cells are longer than the ectoderm and are of two kinds—glandular and digestive.

Nematocysts.—The whole body, and particularly the tentacles, is covered with small projections, from the surface of which are stiff hairs. Each hair is connected with a highly differentiated cell termed the nematocyst or stinging cell. The stiff hair on the surface is called a cnidocil or trigger hair, because when this hair is brought in contact with a water flea the effect is to cause the nematocyst to discharge a long thread, which penetrates the prey, causing paralysis. The fluid which is contained in the undischarged nematocysts is a poisonous secretion. When a stinging cell has been once

discharged, the thread cannot be withdrawn, and so is useless to the hydra, and a new nematocyst must grow from the underlying cells to take its place (Fig. 105).

Locomotion.—Hydra when first introduced into an aquarium wander about more or less irregularly and slowly collect, not far from the surface of the water, on the side of the aquarium turned toward the window. Under normal conditions of light and food, the hydra now become less active and may remain for some time with scarcely any change of position. As their food supply becomes exhausted, hydra begin to wander about in search of food, even

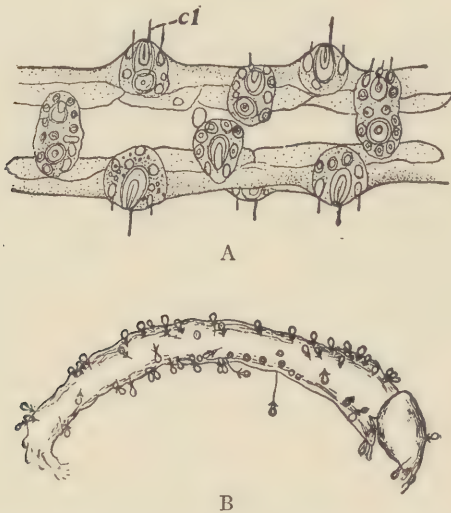


FIG. 105.—Nematocysts and their action: *A*, portion of a tentacle showing the batteries of nematocysts; *cl*, cnidocyte; *B*, insect larva covered with nematocysts as a result of capture by hydra. (From Jennings.)

floating about and sinking to the bottom of the aquarium to gorge themselves with organic sediment.

Careful observation of hydra as it moves about reveals that it usually employs a definite series of bodily movements. These Wagner describes as follows: "The body, expanded and with tentacle expanded, bends over to one side. As soon as the tentacles touch the bottom they attach themselves and contract. Now one of two things happens: (1) The foot may loosen its hold on the bottom and the body contract. In this manner the animal comes to stand on its tentacles with the foot pointing upward. The body

now bends over again until the foot attaches itself close to the attached tentacles. These loosen in their turn and so hydra is again in its normal position. Trembley, in 1791, described these movements. (2) In the other case the foot is not detached but glides along the bottom until it stands close to the tentacles, which now loosen their hold. The result in either case is the same. By one such maneuver hydra travels a distance several times its own length when contracted. Hydra is further able to make slower journeys by gliding about on its own foot without aid from the tentacles. This movement is very slow, and noticeable only on very close observation. Nevertheless, hydra travels considerable distances by means of it."

Reproduction.—Reproduction in hydra may take place in two ways—the asexual and the sexual.

Asexual Method.—The asexual process consists of the formation of a new hydra without fertilization. The usual method is the growth of one or more buds, which first appear as slight bulges in the body wall. These gradually grow in length, small tentacles arise on the free end and a mouth appears. During all this time the gastrovascular cavity of the parent is connected with that in the bud. The rate of growth is largely determined by the amount of food which the parent hydra secures. After a time the bud becomes detached from the parent and leads an independent existence; it is like the parent in all particulars except size and possibly in the number of tentacles. There is also evidence to show that hydra may divide longitudinally as shown in Fig. 109.

Sexual Method.—The sexual method of reproduction takes place through the union of sperm and egg cells. The sperm cells are found in small conical, whitish elevations a short distance below the tentacles. When the sperm cells are set free in the water they continue active for two or three days. The egg begins to grow from one of the small ectoderm cells and gradually increases in size through the engulfing of the surrounding cells. The nuclei of these eaten cells remain for some time in the egg cytoplasm (Fig. 108). Usually but one egg cell reaches maturity. When the egg is mature it undergoes maturation in a manner similar to that described for the frog's ovum, after which the egg is exposed by the breaking down of the outer ectoderm cells. Fertilization takes place as soon as a sperm cell penetrates the cytoplasm, usually within a couple of hours. Segmentation follows in a regular manner until the embryo is hatched. The embryo leaves the parent and remains

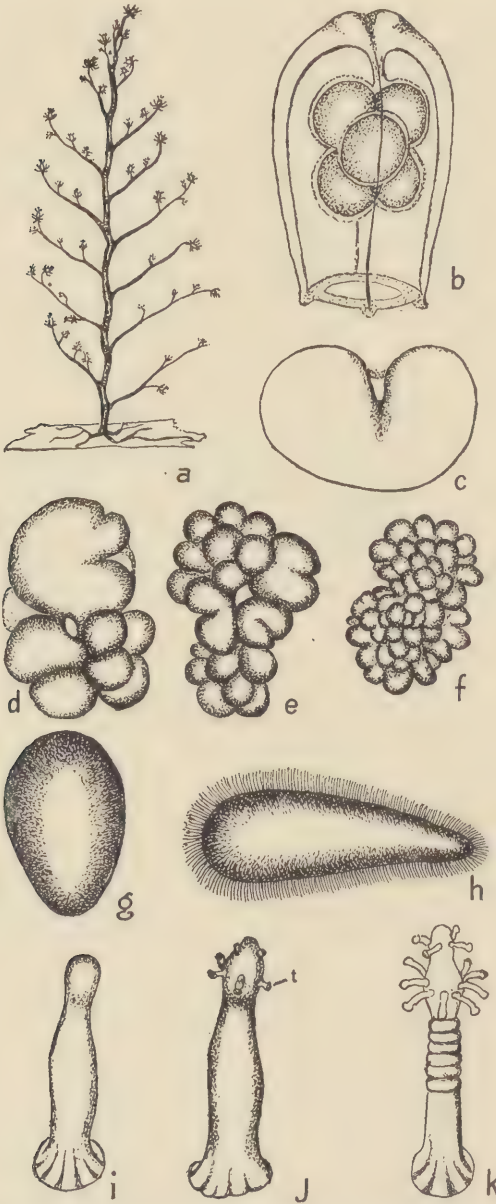


FIG. 106.—*a*, *Pennaria tiarella*; *b*, medusa with eggs; *c-f*, segmentation stages of embryo; *g-h*, the planula stage; *i-k*, the planula becoming a polyp. The medusa is grown asexually by the hydroid, *a*, while the medusa, *b*, grows either eggs or sperms. The fertilized egg in turn develops into a hydroid instead of a medusa. This method of reproduction is known as the alternation of generations and is illustrated in the stages *a* to *k*. (After C. W. Hargitt.)

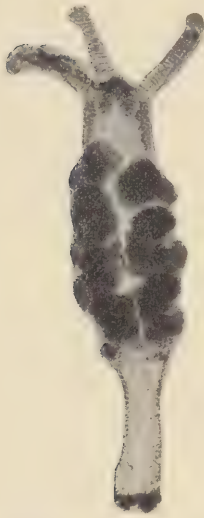


FIG. 107.—Photomicrograph of hydra, showing eggs.



FIG. 108.—The egg of a hydra at about the time that it breaks through the ectoderm and previous to maturation. The nucleus at this time stains lightly, and the pseudo-cells, the remains of the young eggs that have been engulfed by this egg, appear as irregular dark bodies in the cytoplasm. (After Wager.)

inactive for some time before it becomes transformed into a hydra. Any animal that bears both sperms and eggs is neither male nor female but both, that is, bisexual. The term hermaphroditism is used to describe this condition.

Regeneration.—Closely associated with the origin of a new hydra, especially by the asexual process, is the power of regrowing parts that have been lost through mutilation. Hydra can be cut into

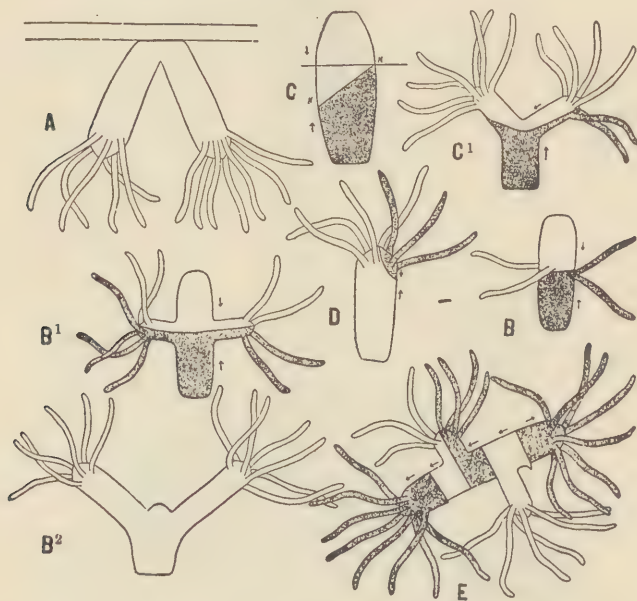


FIG. 109.—A, hydra split in two, hanging vertically downward; later, the halves separated completely; B, two posterior ends united by oral surfaces; B¹, same, it regenerated two heads, each composed of parts of both pieces; B², absorption of one piece leading to a later separation of halves; C, two posterior ends united by oblique surfaces; later, one piece partially cut off, as indicated by line; C¹, later still, two heads developed; D, similar experiment in which only one head developed; E, five pieces united as shown by arrows; four heads regenerated, one being composed of parts of two pieces. (King.)

two parts and each part will regrow the part lost. Closely related to regeneration is the ease with which two hydra may be grafted together. This can be done in a variety of ways, often resulting in many-headed forms (Fig. 109 E). These cells of the hydra retain the primitive power of growth, although they have taken up definite positions in the organism, and their usual work is not that of reproduction. Closely related to this power of regeneration is

that of regrowing the entire animal from isolated cells or clusters of cells. In some of the simple sponges and hydroids Wilson has been able to regrow the entire animal from chopped pieces that were strained through cheesecloth (Fig. 111). Such experiments clearly indicate that the body cells have the power to regrow a new individual, which is a power that is usually confined to germ cells. These experiments in grafting and regeneration in the hydroids

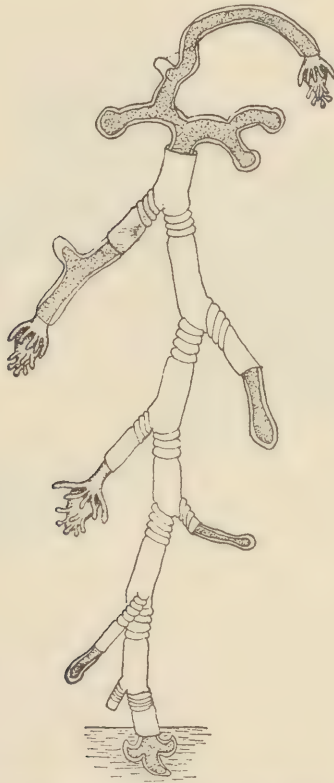


FIG. 110.—*Pennaria* anchored to the bottom of the dish by the distal end, showing regeneration. Unshaded portion is the old stem. (G. T. Hargitt.)

were the beginning of the study of grafting and the study of living isolated cells which, while yet in its infancy as a branch of investigation, has yielded an extensive number of facts that are rapidly becoming of great service to man.

Physiology.—It is interesting to compare the functional activities of hydra with the highly organized frog and the simple paramecium. When the hydra is hungry it goes through characteristic movements even when brought in contact with a piece of filter paper soaked in beef juice. The several movements of the tentacles and the distal part of the body associated in carrying such a piece of filter paper

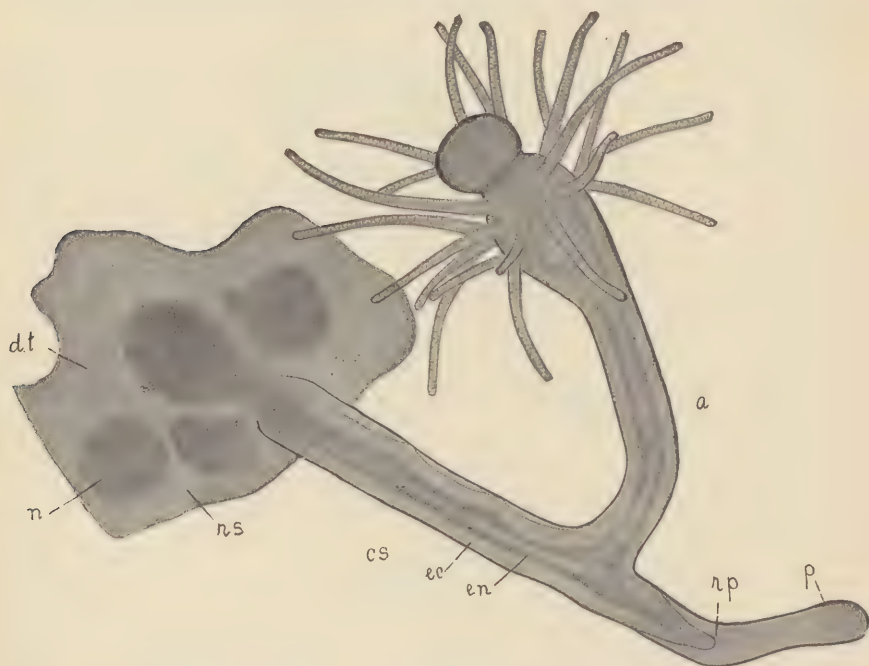


FIG. 111.—After the hydroid has been chopped into small pieces it is strained through gauze. The hydroid flesh streams through the pores of the gauze and falls into a dish as a fine sediment. This sediment consists of the cells of the body of the hydroid variously dissociated. This figure shows the amount of regeneration that took place in six days in *Eudendrium*. *n*, nodule of living tissue; *ns*, general mass; *cs*, outgrowth which has divided and produced, *a*, hydranth on one branch; *ec*, ectoderm; *en*, endoderm; *p*, perisarc of outgrowth; *rp*, regeneration point. (H. V. Wilson, in *Journal of Experimental Zoölogy*.)

into the mouth are called the food reactions. When a passing cyclops or cypris touches one of the tentacles it is shot full of nematocysts, which paralyze it. The tentacle that is held by its nettling threads to the animal bends and carries the food to the mouth. In this process the other tentacles often assist. As the prey touches the edges of the mouth it is passively swallowed.

The gland cells in the endoderm now become active and those nearest the mouth pour out a slime which seems to act like the protein-dissolving ferments in the frog. We judge that there are no carbohydrate enzymes present in hydra, since starch grains when fed to hydra are ejected unchanged. The action of the slime enzyme is to dissolve part of the food and to break up the rest into minute



FIG. 112.—Plexus of nerve cells in the ectoderm of *Hydra fasca*; the parallel lines represent the longitudinal muscle fibers on the supporting lamella. (From K. C. Schneider.)

fragments. The dissolved food is absorbed into the cells and is distributed to the various parts of the body. It used to be customary to state that some of the endodermal cells could engulf small particles of food which were digested by the surrounding protoplasm. But the nature of the food, being chiefly minute crustaceans, makes it difficult to see how such a form of digestion could take place. Repeated observations, extending over many years, by Prof. C. W. Hargitt have failed to detect a single instance of the engulfing of particles of food by these endodermal cells. The undigested residue of the hydra's meal is defecated through the mouth.

There are no special cells that take charge of respiration and excretion in hydra, but as the whole animal is immersed in the water, oxygen is taken in by any of the cells from the water and waste substances are cast off into it. In the frog the skin and lungs absorb oxygen from the air, and the skin at times from the water. The

skin and lungs cast off carbon dioxide and the kidneys nitrogenous wastes.

The fact that certain cells are specialized to form even a diffuse network of nerve cells indicates the beginning of differentiation of function. By means of the nerve plexus the tentacles can act in harmony in capturing prey, in moving from place to place and in responding to various external stimuli (Fig. 112).

The question has often been raised as to the power of an animal like the hydra to initiate movements from within its own body. Jennings has made a special study of this form of movement in

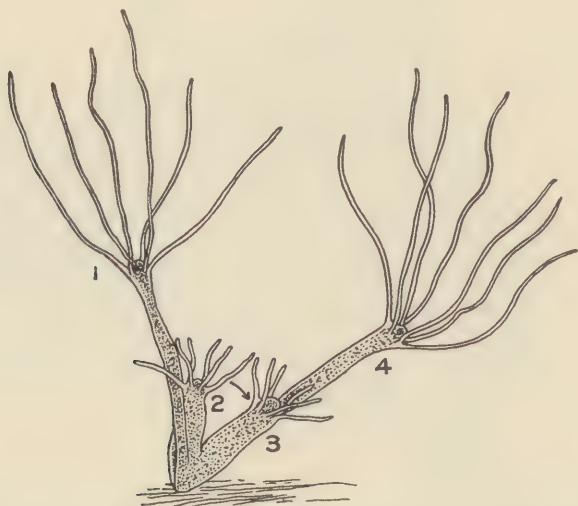


FIG. 113.—Spontaneous changes in an undisturbed hydra. Side view. Extended animal (1) contracts (2), bends to new position (3), and then extends (4). (After Jennings, "Behavior of the Lower Organisms," Columbia University Press.)

hydra and believes that spontaneous movements can be observed. The body and tentacles may contract suddenly and then slowly expand. This is illustrated in Fig. 113.

The hydra exhibits another physiological habit that is not present in the frog. This is the peculiar relation that exists between the hydra and the greenish and yellowish chloroplastic corpuscles. These chloroplastic bodies are minute unicellular plants (*Chlorella vulgaris*). They are found in large numbers in the bases of the endoderm cells. These bodies are passed on to the offspring through the egg cell or in budding. What is the relation of these cells to

the hydra? The hydra is able to carry on all of its life processes with no apparent inconvenience from these cells. Ever since it was shown by placing a hydra in a weak solution of glycerin that it could live without these bodies, there has been doubt about regarding such plants as beneficial to hydra. The usual explanation has been to regard these very much degenerated plants as using waste carbon dioxide in the manufacture of starch. This waste is given off by hydra. The oxygen set free in the starch-making process is used by the hydra. If the process is mutually beneficial then we have a condition which is described by the term symbiosis. If the benefits are mostly or wholly one-sided then the correct term to express the relationship is parasitism.

Winter Life of Hydra.—During the winter of 1916–1917 the writer had an opportunity to study the brown hydra during each month from November to March. The individual animals came into the State Hatchery at Saranac Inn, N. Y., through the in-take pipe located in Little Clear Pond. These hydra were observed to be in an active state of asexual reproduction during each of these winter months. They were feeding upon minute crustaceans, *Cyclops americanus*. This study would lead us to believe that these minute and delicate organisms are active throughout the entire year.

CHAPTER XV.

THE "WORM" GROUP—THE EARTHWORM AS A TYPE.

IN all of the older zoölogies there are included under this general term of "Worms" the animals that are arranged in this chapter under phyla IV, V, VI, VII and IX. There was no real relationship, but the several members looked like worms and were so classed. They all lack well-differentiated body regions, such as a head for example. Some of the parasitic members will be described in the chapter on Parasitism. For the purpose of understanding the plan upon which the body of the worm is organized the common earthworm, *Lumbricus terrestris*, is the best example. This species is widely distributed in Europe and is reported in North America from Newfoundland, Massachusetts, Illinois, New York and Mexico.

External Morphology.—The body of the earthworm is long and cylindrical. When crawling it constantly keeps a given surface in contact with the ground; this surface is known as the ventral and the opposite the dorsal. The earthworm is said thus to possess dorsoventral differentiation. There is no well-defined head, trunk or tail. The mouth is located on the anterior end, and internally there are structures which are usually confined to the head region, and so the earthworm is said to have anteroposterior differentiation. The most conspicuous external structural feature of the earthworm is the presence of successive rings varying in size. These rings are termed somites and are the external expression of important internal arrangements of the organs. Animals which have somites are said to exhibit metamerism. This tendency to have the same structure repeated must have taken a firm grip on all of the animals that have evolved from the worm stage, as evidence of this plan of structure is continually cropping out. Metamerism is found in all of the arthropods and vertebrates, including man. For this reason alone the earthworm should be studied, as it helps one to understand many otherwise strange structures, such as the segmental arrangement of the muscles in fishes and all vertebrate embryos. The vertebræ, the paired spinal nerves, and intercostal bloodvessels are good examples of metamerism in man.

Habits and Special Senses.—In this connection every student should read Darwin's *Earthworms and Vegetable Mould*. The earthworms are nocturnal in habit and seldom leave their burrows in the ground except during the breeding season. During the daytime they are to be found near the opening of the burrow, but as dry summer comes on they move deeper into it. Earthworms hibernate singly or in numbers below the frost line. They are able to recognize the difference between day and night, although they do not have eyes even in a rudimentary sense. There are a number of specialized nerve cells in the skin that are connected with the nervous system. Structurally these nerve cells are all much alike, yet the worm is able to recognize, day and night, certain smells, also jars, and is very sensitive to touch in the head region. The fundamental protoplasmic property of irritability is here concentrated in certain

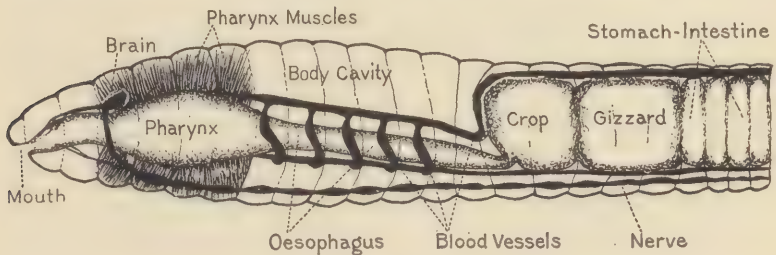


FIG. 114

cells in the skin, but these have not become differentiated into the well-known eyes, ears, etc., of the higher animals, and yet the earthworm is able to act as if it had special sense organs. The earthworm has been studied a great deal because of its very simplicity in an attempt to understand just what is essential to a special sense. Here the physiological differentiation has preceded a structural differentiation. A similar case is found in the fact that we can detect the difference between hot, cold, pressure, touch and pain in our own skin, and neurologists are not able to find definite structural differences between the nerve processes that enable us to recognize these several stimuli. On the other hand the well-defined eyes and ears enable all of the higher animals to have more accurate information with reference to their surroundings.

Organ Systems.—The organ systems of the earthworm are briefly given because most of the parts are easily worked out in the laboratory. The plan of the body is that of two telescopically disposed

tubes, a larger one typifying the body wall and a smaller one the digestive tube. Between these two tubes there is a considerable space, the coelomic cavity. The coelomic cavity is partitioned by numerous dissepiments, thin sheets of connective tissue extending from the groove between the somites to the digestive canal. The blood flows through bloodvessels, well defined in the main, and the dorsal vessel acts like a heart in the way that it contracts and expands, thus forcing the blood along. The coelome is also filled with a kind of lymph or blood, which circulates by means of small openings through the dissepiments; it contains numerous white blood corpuscles, which have the power of changing their shape and

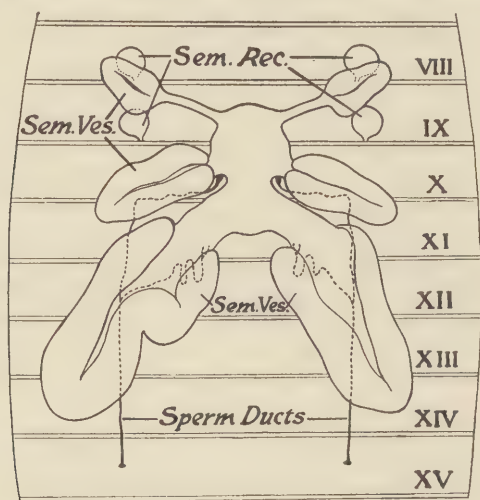


FIG. 115.—Diagram to show relation of male reproductive organs. VIII–XV, somite numbers. *Sem. Rec.*, seminal receptacles; *Sem. Ves.*, seminal vesicles.

migrating through the tissues of the body. They are often called leucocytes or phagocytes. The waste leaves the body through the skin and well-defined nephridia located in each somite except the first two or three. The nervous system consists of a ventral nerve chain, with a ganglion for each somite. From each ganglion branches are given off. In the second to fourth somites there are the following changes: the ganglion in the fourth somite is much enlarged and is called the subesophageal; the two ganglia in the second-third somites are dorsal to the digestive canal and are called the supra-esophageal ganglia or "brain." The brain ganglia are connected with the subesophageal by commissures.

Reproduction.—The earthworm has both male and female organs of reproduction, and because of this fact is designated as hermaphrodite. The ovaries are paired organs, minute and pear-shaped, and situated in the thirteenth somite. As the eggs mature they escape from the ovaries and drop into the funnel-shaped openings of the oviducts, which lead to the exterior on the fourteenth somite. The four spermaries are minute flattened bodies in the tenth and eleventh somites. The immature sperm cells leave the spermaries and are retained in three seminal vesicles until mature. The sperms are carried to the outside through a pair of sperm ducts opening on the fifteenth somite. In the ninth and tenth somites there are two pairs of small flask-shaped bodies called seminal receptacles. These bodies have no structural connection with any of the other reproductive organs.

Although the earthworm is hermaphroditic it is not self-fertilizing, for there must be an exchange of sperms. This is effected in copulation, when the seminal receptacles are filled with sperms from another animal. As the egg-laying period approaches the clitellum secretes a viscid mucus, which hardens and toughens on exposure to the air, thus forming a membrane. This membranous girdle is pushed forward, receiving eggs from the oviduct and sperm cells from the seminal receptacles. In this way the eggs are fertilized by sperms from another animal. Finally the capsule is pushed from the head end of the worm, each end contracting as it leaves the animal to form a cocoon. In this cocoon the embryos grow, feeding on the enclosed food and devouring each other until usually but one reaches maturity.

During the formation of the embryo from the fertilized ovum the changes are regular and follow a distinct plan. After segmentation has taken place for a time the mass of cells takes up a regular arrangement so that definite terms are used to describe the conditions. The cells on the outside are the ectoderm cells and those within the endoderm. After further growth a middle layer (mesoderm) is recognized and the embryo is said to have three germ layers. From each of these germ layers distinct parts of the body arise to illustrate:

Ectoderm	{	Nervous system.
		Part of nephridia.
		Epidermis.
		Lining of mouth and vent.

Regeneration.—The earthworm is an interesting animal in which to study this power to regrow lost parts, for if any of the first seven or eight somites are removed all will be regrown, but when more are cut off only this definite number form again. Thus if the first fifteen somites are removed, seven or eight will grow and the intervening ones will always be lacking, thus rendering the animal sterile. When somites are removed from the posterior end the regenerated part is at first composed of a very few somites. The terminal somite contains the new anal opening and new segments are formed just in front of this terminal somite, the youngest being the one next to the end. This method of adding somites continues until all of those removed have been replaced. The worm cannot be

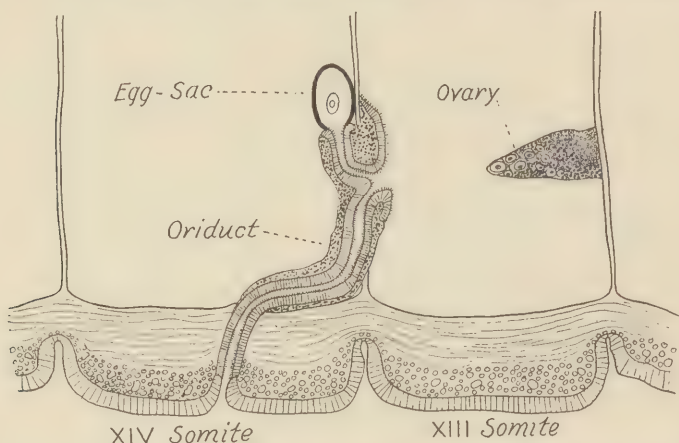


FIG. 116.—The female reproductive organs of the earthworm. As the ova mature they drop out of the ovary and are carried by the cilia of the oviduct into the egg-sac, where they are stored until after copulation.

split lengthwise and live. Hydra may also be studied to advantage in connection with this power of regeneration; or if hydra are not available, the flatworm, planaria, is excellent.

Histology.—In the histological analysis of the frog definite tissues were discovered as the several organs were studied. In a similar study of the earthworm definite tissues are found, each having its own position in the body (Fig. 117).

The following tissues are found in the earthworm: columnar, ciliated and pavement epithelium, muscular, nervous and blood, which can be easily studied. It is not easy to differentiate the connective tissue. In a diagrammatic cross-section the arrangement of these tissues is indicated. The body of the earthworm is covered

with a secretion that hardens into a tough membrane, the cuticle. There are no cells in the cuticle, so that it cannot be termed a tissue. Immediately under the cuticle is a modified columnar epithelium containing special slime cells and sense cells in addition to the regular columnar cells. Next follows a circular and longitudinal layer of muscle. In the first the cells are cut lengthwise, while in the second they are cut crosswise. The inner end of the longitudinal muscle layer is limited by the pavement epithelium, which appears in section as a line. These several layers constitute the body wall. On the ventral surface the body wall is indented to allow the setæ to pass out. In the center of the section is the digestive canal, which is best studied back of the clitellum. A large bloodvessel

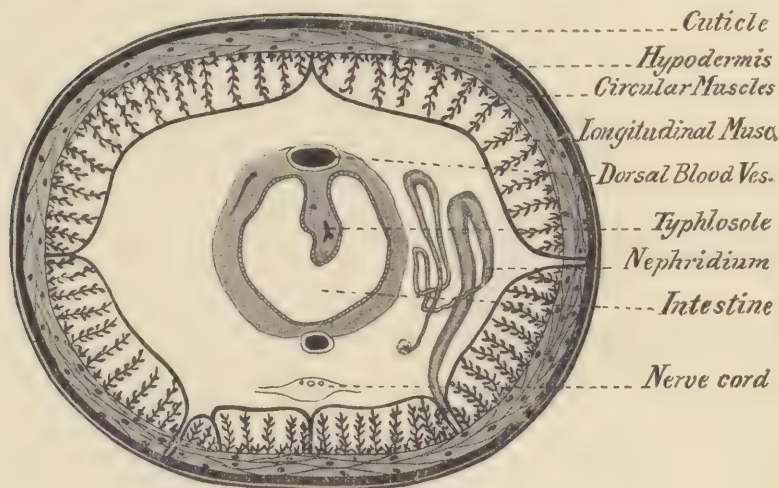


FIG. 117.—Diagrammatic cross-section of earthworm.

marks the dorsal region while a small one, often detached in cutting, is on the ventral side. The intestine is usually folded in this region, the fold bending in from the dorsal surface. This fold is termed the typhlosole. The wall of the intestine is composed of a glandular epithelium on the outside and a columnar and ciliated epithelium on the inside. Between these two layers a few scattering muscle cells and bloodvessels are found.

On the ventral surface of the body wall is found the section of the nerve cord. This is a double cord, which gives off nerves in each somite. Special stains are necessary to make out the details which are shown in Fig. 118. There are definite cells that send

their processes out to the skin, where they receive the stimuli that have been transmitted by the peripheral skin sense cells. Other nerve cells send their processes to the muscles. A very few nerve cells do not leave the nerve cord but connect the adjacent ganglia with each other. These are the associational fibers. The same terms of afferent and efferent that were used in describing the frog's nerves can be applied here. The earthworm shows a marked

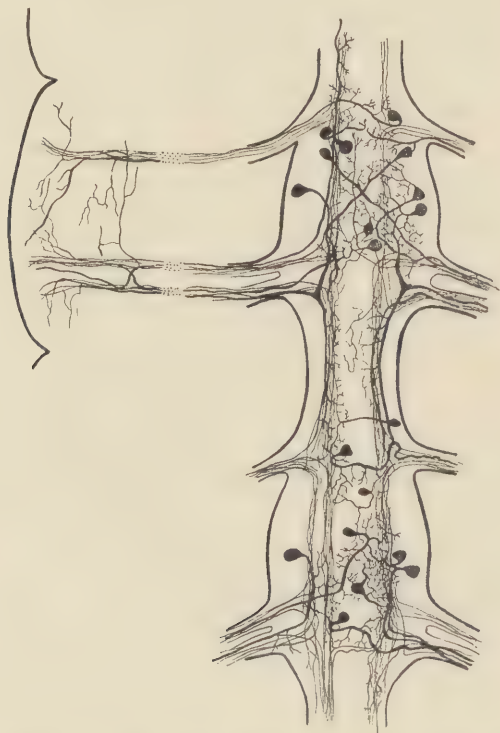


FIG. 118.—Two ganglia in ventral nerve chain. The sensory nerve fibers of the skin end in the dendrites of the motor and coördinating cells. (From Retzius.)

advance over the hydra in that the nerve cells are collected into a definite organ and in that definite work is assigned to given neurons. The several ganglia are in communication with each other, but in a poor and incomplete fashion as compared with the frog. In this sense the earthworm stands as an illustration of the beginning of the development of the associational fibers, which later become so important in the development of the nervous system.

Intelligence of Earthworms.—Some interesting experiments have been made on the earthworm to ascertain to what extent it can learn from experience.

Yerkes designed a T-shaped labyrinth of plate glass, with runways 2 centimeters wide, which was used to test the ability of earthworms (*Allolobophora fetida*) to “learn” to follow a simple path and to avoid an injurious chemical (or electrical) stimulus by reacting negatively

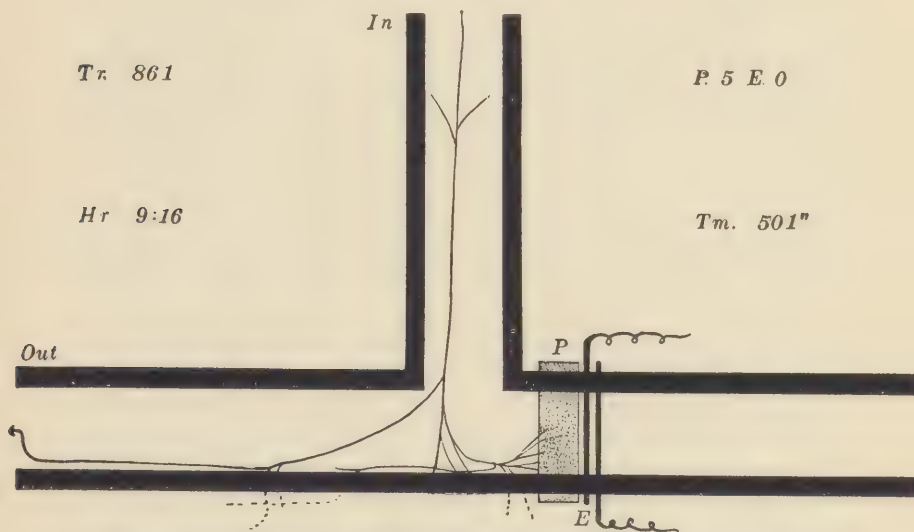


FIG. 119.—Diagram of T, showing path followed by earthworm in first trial after removal of the brain. *E*, pieces of copper wire serving as electrodes, insulated and kept at a fixed distance from one another by rubber; *P*, strips of sandpaper. (Yerkes.)

to a peculiar tactile stimulus which regularly preceded the chemical. He had in mind these two questions: (1) Can the worm profit by experience; (2) can it “associate” the tactual stimulus with the chemical and acquire the habit of regularly responding to the sandpaper as though it anticipated the effect of the salt? From October 12, 1911, to April 30, 1912, a single worm was given 850 trials in passing through the labyrinth under various conditions. The results showed that the worm was capable of acquiring certain modes of reaction which involve a definite direction of movement and the association of two stimuli. He says: “In view of this positive result of training it was deemed worth while to proceed with the next step in the investigation—namely, amputation of the anterior segments, with the ‘brain,’ in order that the relation of the habit to the

'brain' might be studied. Forty hours after the operation it seemed desirable to resume the experimentation. With the apparatus arranged precisely as in the previous series of trials the worm was permitted to enter the T. It moved forward, more slowly and continuously than before the operation, into the middle of the stem. Having reached the common wall of the arms it turned to the left and five times pushed forward to the sandpaper, each time withdrawing upon contact. As it searched with the cut end for a way of escape, the 'tail' became active and moved about as if 'feeling' for a path. Shortly a turn toward the right was made and, with repeated attempts to crawl up the glass wall, the worm approached the exit tube. The instant the 'head' end came in contact with the moist lining of the tube the worm pushed forward as in 'recognition' of the retreat (Fig. 119).

"The correct performance of a thoroughly ingrained habitual act of the kind studied in this investigation is not dependent upon the 'brain' (portions of the nervous system carried by the five anterior segments), since the worm reacts appropriately within a few hours after its removal. As the brain regenerates the worm exhibits increased initiative and its behavior becomes less automatic, more variable. Two months after the removal of the 'brain,' during the last four weeks of which period no training was given, the habits had completely disappeared. Systematic training of two weeks resulted in the partial reacquisition of the original direction habit. The various facts recorded in this investigation indicate that the removal and the regeneration of the first five segments resulted in the development of a worm strikingly different in behavior from the original worm."¹

¹ Yerkes: *The Intelligence of Earthworms*, Jour. Animal Behavior, 1912, No. 5, vol. ii.

CHAPTER XVI.

MOLLUSCA.

General Characters.—The mollusca are known to have existed the early Paleozoic epoch. The mere fact that this phylum was clearly defined at such an early date probably means that their origin and relation to the other invertebrate phyla is lost forever. In this phylum there are more than 60,000 living species.

The mollusca include soft-bodied animals, usually with an external shell; they are also characterized by a general absence of metamerism and by the cœlome being reduced to inconspicuous remnants around the heart and to the lumen of the gonads. The presence of a mantle which secretes the shell, a wide variety of relations between the foot and head (a head being absent in clams), and sexual reproduction constitute the characteristics which distinguish the clams, oysters, snails, octopi, etc., from all other animals.

The fact that clams and oysters are so generally used as food and so frequently cause disease is sufficient warrant for studying this aberrant group in a general course in biology. In this account only such structures are described as are necessary in understanding their method of feeding.

The calcareous shell of the clam consists of a right and left valve, held together by a hinge ligament. The valves are held in contact by adductor muscles, one anterior and one posterior. When these muscles relax the elasticity of the hinge ligament opens the shell. The shell grows in a regular manner so that one can easily tell which region is older. The oldest part of the shell is the small, conical knob, the umbone, just anterior to the hinge ligament. There are many concentric lines of growth on the surface of the shell, each of which marks a brief resting period. The youngest part of the shell is the outer margin. The ordinary clam on the market is from three to five years old, although there are fifty or more lines of growth.

When one valve is removed after cutting the adductor muscles, the inside of the shell appears as noticeably smooth and of a pearly luster. Muscle scars indicate where the muscles were attached. Along the hinge ligament margin various forms of interlocking teeth are found which keep the shell from slipping.

As one examines the soft body of the clam he finds the whole visceral mass covered by a thin membrane, the mantle. The mantle

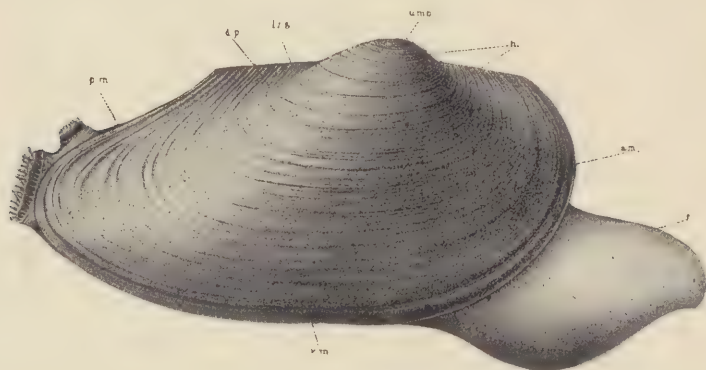


FIG. 120.—*Anodonta fluvialis*. *a.m.*, anterior margin; *p.m.*, posterior margin; *d.p.*, dorsal margin; *v.m.*, ventral margin; *l.i.g.*, hinge ligament; *f.*, foot extended; *umb.*, umbo; *h.*, hinge-line. Notice the position of the two siphons and the shape and size of the foot. (After Simpson.)

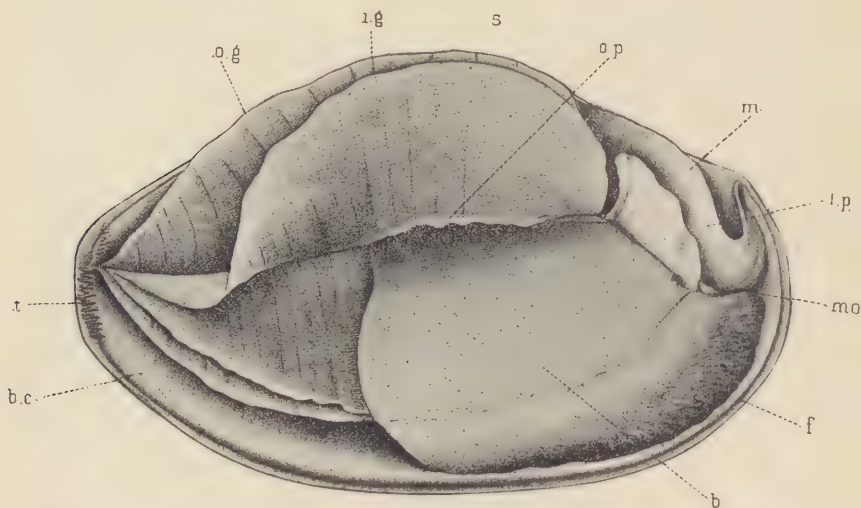


FIG. 121.—*Anodonta fluvialis*, showing the mantle and gills thrown back, exposing the foot, body and labial palps. *f.*, foot; *b.*, body; *i.g.*, inner gill; *o.g.*, outer gill; *b.c.*, branchial cavity; *l.p.*, labial palpi; *m.*, mantle; *mo.*, mouth; *o.p.*, opening through the gills for the passage of the body; *t.*, tentacles of inhalent siphon. (After Simpson.)

is a structure peculiar to the molluscs. It has three general uses: (1) It secretes the shell; (2) it is the main organ of respiration; (3)

to remove foreign matter from the mantle chamber. The two folds of the mantle completely line the shell. On the posterior margin the mantle frequently becomes specialized into two tubes, the dorsal one serving for the escape of wastes while the ventral is the inlet into the mantle cavity for sea-water containing food. These two openings are the excurrent and incurrent siphons. There is a rhythmic movement of the mantle independent of the movements of the shell which is an important factor in setting up a respiratory current and removing waste material and foreign bodies from the mouth chamber (Figs. 118 and 189).

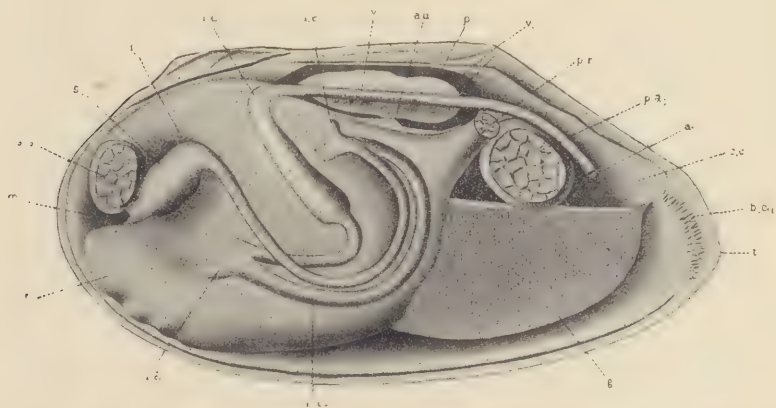


FIG. 122.—*Anodonta fluviatilis* dissected to show intestinal canal. *a.a.*, anterior adductor muscle; *au.*, auricle; *a.*, anus; *b.c.*, branchial chamber; *c.c.*, cloacal chamber; *f.*, foot; *g.*, gill; *i.c.*, intestinal canal; *l.*, liver; *m.*, mouth; *p.*, pericardium; *p.a.*, posterior adductor muscle; *p.r.*, posterior retractor muscle; *s.*, stomach; *v.*, ventricle. (After Simpson.)

The visceral mass of the clam consists of a large ventral muscular foot which merges dorsally into the several organ systems (Fig. 120). On each side of the visceral mass two pairs of gills are attached, their free edges hanging down in the mantle cavity.

Food of Clams and Oysters.—Clams and oysters are passive feeders and possess no organs for seizing food. The cilia on the gills cause a current of water to be drawn in through the incurrent siphon. The water strains into the interior of the gills and finally passes out through the excurrent siphon. As the water in the mantle cavity comes in contact with the mucous secretion on the surface of the gills all solid particles are caught. This mucous secretion is moved by cilia on the gills toward the mouth. On each side of the mouth

there is a pair of labial palps (Fig. 119), which are covered with cilia, and these assist the gill-cilia in moving and directing the food-laden mucus into the mouth. The entire digestive tube is lined with cilia which are probably solely responsible for keeping the food and mucus moving in the digestive canal.

The food of clams and oysters consists mostly of minute plants, diatoms usually predominating. Some authorities state that unicellular algæ, protozoa, eggs and various minute larvæ are eaten. The natural food of the edible clams and oysters lives in brackish water, especially at the mouths of rivers emptying into the sea. Long Island Sound and Chesapeake Bay are two such notable places.

The diseases caused by eating raw *shell-fish* are due to the following causes: Clams and oysters do not feed upon *B. coli* and *B. typhus*, for example, nor do these organisms live as parasites on the clam or oyster. In fact, these bacteria are not even adapted to life in the clam and oyster, for oysters when inoculated with *B. coli* and isolated do not give cultures of the inoculated bacteria after two weeks when kept at room temperature. This would seem to indicate that the disease-causing organisms were carried into the mantle cavity, where they are left by the water, and here they remain until they die. Oysters and clams must become reinfected at frequent intervals to be continuously dangerous as food. The relationship which *B. coli* and *B. typhus* have to the clam and oyster is a purely mechanical one. Clams and oysters will purify themselves in the course of two days if transferred to pure sea-water.

CHAPTER XVII.

THE CRAYFISH.

Kinds and Distribution.—Crayfish have been known to scientists ever since Aristotle wrote about the “Small *Astaci* Which Breed in Rivers.” In the United States there are some seventy species of crayfish, most of which belong to the genus *Cambarus*, there being but five species of the genus *Astacus*.

Faxon says these two genera occupy distinct geographical areas. The genus *Astacus* is found in the old world in Europe and Western Asia as far as the Aral and Caspian Seas and in America in the region west of the Rocky Mountains in the streams draining into Great Salt Lake and the Pacific Ocean. It is thus seen to occupy the western sides of two continents. *Cambarus* is found in North America east of the Rocky Mountains in the region which is bounded on the north by Lake Winnipeg and New Brunswick and on the south by Guatemala and Cuba.

The crayfish are commonly found in streams and ponds, although one species lives in moist meadows in burrows. Economically the *Astaci* are valued as food by foreigners, and crayfish farms are maintained to supply this table delicacy. In the cotton belt, crayfish kill the young cotton plants by eating the tender roots.

Food.—While crayfish act as scavengers, eating various kinds of dead animals, they seem to prefer living animals, such as tadpoles small frogs, insect larvæ, etc. They also prey upon each other. During the daytime crayfish are inactive, but begin feeding at dusk and continue during the night.

General Characteristics.—Among the invertebrates the hydra, earthworm and crayfish are the animals best known to biological students. The reason for this nearly universal familiarity is that each exhibits important fundamental steps in the evolution of animals. The crayfish, in addition, is studied as a type of the most numerous phyla of the invertebrates, the *Arthropoda*, for here are classed according to some authorities more than six hundred thousand different species, all of which have three structural characteristics in common. These are the presence of modified somites, an exoskeleton and jointed appendages.

Modified Somites.—The body of the crayfish is divided into the anterior immovable region, the cephalothorax; and the posterior movable, the abdominal. The somites in the abdomen are all similar excepting the first and last. Each typical somite supports a pair of appendages. It is easy to recognize in the somites of the abdomen the simpler plan that exists in the earthworm. The question naturally arises as to how many somites have united to form the cephalothorax. Inasmuch as a typical somite supports a single pair of appendages, by counting the number of pairs of appendages in this region the problem is solved. Such an enumeration reveals that there are thirteen pairs, not counting the eye-stalk. This means that thirteen somites have united to form this cephalothorax region.

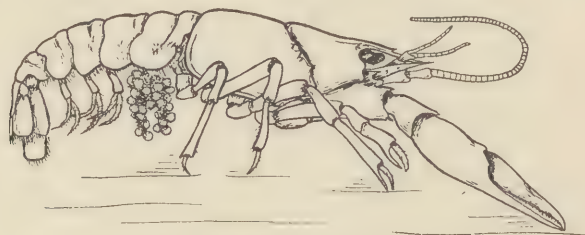


FIG. 123.—Crayfish bearing eggs.

In reaching this important conclusion one must have recourse to the facts of embryology which reveal the primitive and successive changes through which this region has passed. The cephalothorax of the crayfish not only shows how a general body region may have arisen as a modification of somites, but also how the head and thorax as distinct regions may have become differentiated, for there is a distinct groove in the carapace, the exoskeleton of this region, which marks off the head region from the thorax.

Exoskeleton.—The surface of the body is covered with a chitinous cuticle made hard by impregnated lime salts. This peculiar substance is composed of the following chemicals probably having this arrangement: $C_8H_{15}NO_6$. Wherever there is a joint this exoskeleton is thin and flexible, thus allowing movement. Such an external skeleton naturally limits the growth of the crayfish and prevents an increase in size. Yet common observation proves that young crayfish do grow larger. To allow this increase in size the whole of the exoskeleton is shed and the process is known as moulting or ecdysis. In moulting the old skeleton loosens and drops off

while the underlying cells secrete a new covering of chitin. Moulting also takes place in adult crayfish and the process necessitates that the lime be absorbed along the dorsal line of the head-thorax region and that the joints soften. The exoskeleton then splits along the line where the lime has been absorbed, the blood is withdrawn from the limbs and the whole anterior part of the body withdraws from the old shell. The abdominal region is drawn out last. The lining of the esophagus, the stomach and the hind intestine is also removed because they arise through an infolding of the skin. While some of these details do not apply to all Arthropoda, the main facts do.

Jointed Feet.—The scientific term, Arthropoda, describes this easily recognized characteristic. All members of this phylum have more than two pairs of jointed appendages, which in general move by hinge-joints. The appendages of the crayfish also furnish an interesting study in adaptation, as all of them can be shown to have the same general parts at first (Fig. 124).

Apparently the primitive form of appendage is the one found on most of the abdominal segments, called the swimmerets. Such an appendage (Fig. 125) consists of a simple basal protopodite supporting two flattened branches, the outer, an exopodite, an inner the endopodite. The last abdominal pair of appendages is enlarged, although no new structures are added. The same three primitive parts are readily distinguished (see uropod in Fig. 124). In a similar manner the several walking appendages are compared with the typical or primitive abdominal. In these there has occurred the loss of the exopodite and the distinct jointing of the endopodite. Sometimes the terminal joints are opposite and form pincers (Fig. 124). Anterior to the walking appendages occur six pairs that assist the crayfish in securing, tearing and crushing its food. Fig. 124 shows the form and parts of one of the three maxillipeds and the mandible. In a similar way the two antennæ are compared with the same typical abdominal appendage. Each of the antennæ has the endopodite greatly enlarged and double in the smaller one (Fig. 125). The only evidence of the exopodite in these two appendages is the large scale at the base of the large antennæ. It is expected that this general description of the similarities between the appendages will be supplemented by a detailed laboratory study.

A full comparison of the appendages of the crayfish necessitates a thorough knowledge of their embryology. In this way one determines which parts have been lost and which retained. Fig. 123

shows the walking appendages of the lobster with both an endopodite and exopodite. A similar stage in the development of the crayfish shows the same parts. While in the adult crayfish the several appendages have become adapted to swimming, walking, food-getting, feeling and tasting, yet a study of their development clearly indicates that each one is derived from the primitive abdominal type.

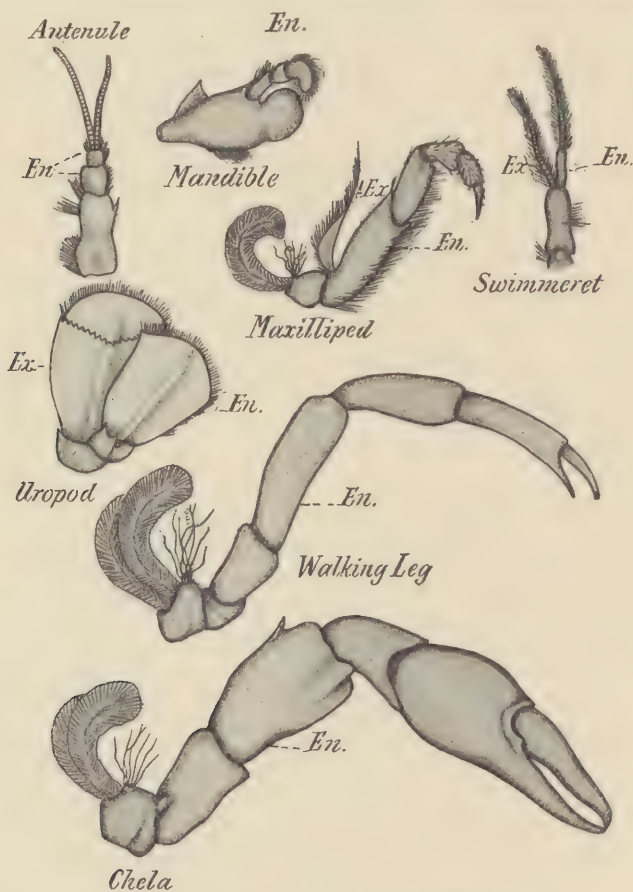


FIG. 124.—Appendages of crayfish.

In this comparison of the appendages of the crayfish in which highly specialized feet are shown to have parts in common with all the rest of the appendages, an important method of explaining many of the specializations in plants and animals is illustrated. Such structures as the appendages of the crayfish are termed *homologous organs*,

because they have had a common embryonic origin. The fact that in the adult stage these organs are widely divergent in appearance and use does not interfere with the more fundamental fact of the common embryonic origin. (For a further discussion see Homology, p. 247).

Organ Systems.—The several organ systems of the crayfish are all clearly defined, and in the nervous, reproductive and excretory systems are of a higher order than in the earthworm (Fig. 114).

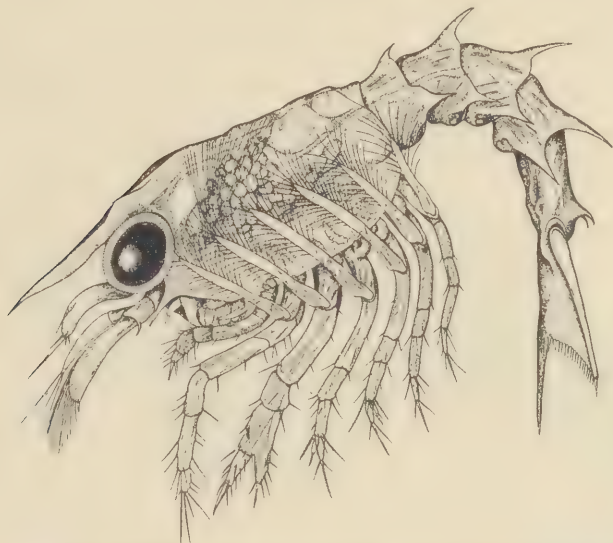


FIG. 125.—First larval stage of lobster, showing the biramus appendage in the thoracic region. The embryonic exopodite disappears.

The mouth is ventral in position and bounded by modified appendages. It opens into a short esophagus that expands into a capacious stomach. The stomach is divided into two regions by a constriction. The anterior is the larger and known as the cardiac stomach, while the small or posterior is the pyloric. A straight intestine extends from the pylorus to the anus located on the last abdominal somite and opening ventrally. In the cardiac stomach the chitinous lining is thickened in certain parts to form ossicles. These are arranged in such manner that the food is chewed by them. The several ossicles constitute the gastric mill.

On each side of the stomach is located a pair of digestive glands sometimes called the liver. Each gland consists of three lobes. The glandular epithelium lining the numerous tubules in each gland

secretes a digestive fluid that is very complex. The food of the crayfish consists of proteins, carbohydrates and fats, consequently it is not correct to designate this gland as a liver but rather as a pancreas. The digestive enzymes of this gland are probably the following: (1) A protease enzyme, which acts upon the proteins; (2) a lipase, the fat-emulsifying enzyme; (3) cytase, a cellulose-dissolving enzyme.

The crayfish breathes by means of gills contained in a narrow chamber protected by the overhanging carapace. The two rows of gills are named from their attachment as podobranches when fastened to the protopodites and constitute the outer row. The second row is made up of the arthrobranches, as they are attached to the articular chitin at the base of the appendages.

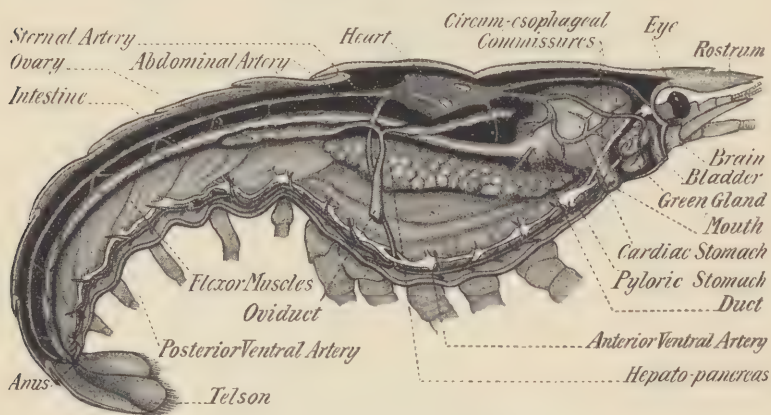


FIG. 126.—Median section of crayfish.

Each gill consists of numerous small filaments arising from a central axis. Two bloodvessels penetrate the base of each gill and give off a branch to each filament. The blood courses in through one and out through the other, during which process oxygen is taken from the water and waste carbon dioxide given off. The gill is an outpushing of the body wall, which is shown by the fact that it contains the same layers as the body wall.

The nephridia of each somite in the earthworm are limited in the crayfish to a single pair located in the anterior ventral part of the head. Each gland is divided into a glandular portion and a thin-walled bladder. The excretory duct opens on the ventral surface of the basal segment of the large antenna (Fig. 126).

The colorless blood-containing ameba-like blood corpuscles carry on the usual functions of the blood. There are well-defined arteries and a definite heart that beats rhythmically. Valves in each artery as they leave the heart prevent the blood from flowing back into the heart. After the blood is carried to the tissues it passes into irregular spaces termed sinuses. From the sinuses it is carried to the gills and from the gills to the pericardial sinus. The heart has several openings, the ostia, through which the blood enters the heart and is prevented by valves from escaping.

The muscles which enable the many joints in the appendages to bend in so many directions are numerous and arranged in pairs. Large muscles to flex the abdomen in swimming occupy nearly all of the space in the abdomen. These muscles are the chief source of food for man.

The crayfish, unlike the earthworm, normally contains the reproductive organs of but one sex. There is a single testis located beneath the pericardial sinus. It consists of two lobes on the anterior end and a single medial lobe posteriorly. From each side a coiled vas deferens passes to the protopodite of the fifth pair of walking appendages. The ovary is located similarly in the female and has a short, straight oviduct that opens in the protopodite of the third walking appendage. When crayfish copulate the male deposits sperms in a cavity on the ventral surface of the cephalothorax called the seminal receptacle. Here they are stored from October until egg-laying in the spring. Previous to egg-laying the female cleans the ventral surface of the abdomen and a slime is secreted by cement glands located in the abdominal appendages. This slime is spread over the swimmerets. The female then lies on her back and the one to six hundred eggs become attached to the hairs. Just how the sperms are distributed to the eggs is not known. The female keeps the eggs aerated and free from dirt. The eggs hatch in from five to eight weeks (Fig. 123).

The position and general morphology of the nervous system reminds one of the simple series of nerve ganglia in the earthworm. The series of ganglia in the abdomen are found in the six somites, regularly distributed. But this simple arrangement is not found in the cephalothorax, for the primitive somitic simplicity is lost in the fusion of two or more ganglia into single large nervous masses. This is particularly evident in the ganglia beneath and above the esophagus. Five thoracic ganglia can be recognized, but there are thirteen somites in the cephalothorax, so that the natural inference

is that the brain and subesophageal ganglia together represent these eight remaining primitive ganglia. This is on the assumption that

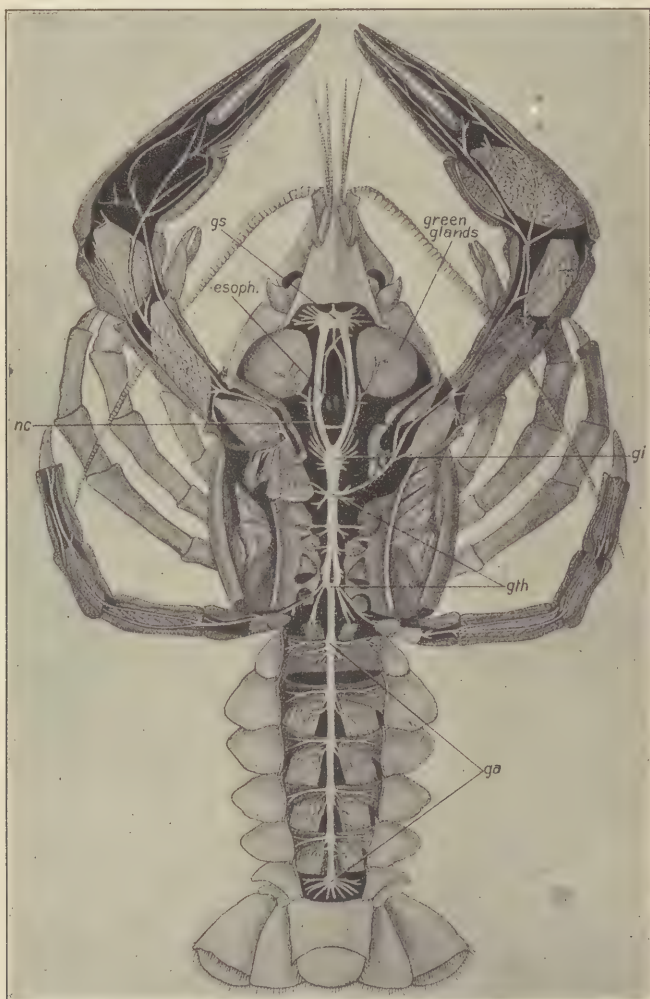


FIG. 127.—Nervous system of European crayfish. *esoph.*, esophagus; *ga*, abdominal ganglia; *gi*, infra-esophageal ganglion; *gs*, supra-esophageal ganglion; *gth*, thoracic ganglia; *nc*, nerve collar. (After Wilhelm Klein.)

each somite originally contained a single ganglion, for which there is a good deal of embryonic evidence. From each ganglion several pairs of nerves pass off, and from the brain and subesophageal ganglion

many branches. The eye, the antennæ and even the stomach receive nerves from the brain. The internal structure of the ganglia of the crayfish shows many more association nerve cells than are present in the earthworm, which is the real test as to which is the higher.

The crayfish shows a marked advance over the earthworm in the development of sense organs. Sense organs of touch, smell, taste, equilibrium and vision are all present. The entire body is sensitive to touch, especially the mouth parts and ventral surface of the abdomen. This sense is located in specialized hairs. Smell and taste are so closely allied that it is proper to designate them by the single term chemical sense. When meat juices are applied to the various parts of the body definite responses are made, and in some instances a series of movements follows which are well described as the feeding reflexes. The chemical sense is better developed in the mouth appendages than anywhere else. In the base of each small antenna is an open sac containing over 200 hairs. Each hair is supplied with a nerve. Small bits of sand are found in the sac. The whole structure was early called an auditory organ. Recent studies have failed to prove that the crayfish hears. When the ear sacs are removed or the ear nerves cut the crayfish swims in nearly any position, apparently just as well upside down as right side up. This suggests that these organs are for balancing or informing the crayfish when it is in its normal upright position. This is not an exclusive sense function of the crayfish, but is present in some jellyfish, snails and vertebrates.

The eye of the crayfish is on the end of a movable stalk. It is described as a compound eye because there are about 2500 distinct visual elements united in each eye. The external skeleton of chitin is transparent over the end of the eye-stalk, and for this reason is called the cornea. Fine lines divide the cornea into four-sided areas, called facets. Each facet corresponds to the individual visual element known as an ommatidium. The compound eye produces an erect mosaic, as all of the rays of light that impinge on the pigment in each ommatidium are absorbed. The only rays that are able to reach the sensitive part are those that pass directly through the center of the cornea because such rays reach the optic nerve. Each ommatidium gives an incomplete picture of an object, but when the many partial pictures are united the whole object must appear as a mosaic. Such eyes are well adapted to detect movement in an object, as any change in position of a large object would be recorded in most of the 2500 ommatidia.

REFERENCES TO CRAYFISH.

ANDREWS, E. A.: Breeding Habits of Crayfish, *Am. Nat.*, 1904, vol. xxxviii. The Keeping of Crayfish for Class-room Use, *Nat. Study Ser.*, 1906, vol. ii. The Young of the Crayfishes, *Astacus* and *Cambarus*, *Smithsonian Cont. to Knowledge*, 1907, vol. xxxv.

HERRICK, F. H.: Natural History of Lobster, *Bull. Bureau of Fisheries*, 1909, vol. xxix.

ORTMAN, H. E.: The Crawfishes of the State of Pennsylvania, *Memoirs Carnegie Museum*, Pittsburgh, Pa.

PEARL, RAYMOND and CLAWSON, A.B.: Variation and Correlation in the Crayfish, with Special Reference to the Influence of Differentiation and Homology of Parts. Octavo, 70 pages, 8 text figures. Published 1907. Price \$1.00. Carnegie Publication.

CHAPTER XVIII.

INSECTS.

Number.—If the estimate of over 400,000 as the number of the different species of insects is even approximately true, they form a class of animals more numerous than all the rest of the animal kingdom. While it is evident that one cannot hope to become acquainted with such a large number of separate species, it is, however, very easy to recognize an insect. Inasmuch as they have world-wide distribution and play such an important role in the life of man, it is desirable to know a few general facts about them.

General Characters.—One of the most remarkable facts concerning this numerous class of animals is their marked similarity. There are three distinct regions easily recognized—head, thorax and abdomen. In general the head bears the organs of special sense, of prehension and of mastication; the thorax, the organs of locomotion; the abdomen, the organs of reproduction. Metamerism as shown for the crayfish is present, although so greatly modified that one must study the embryonic stages to be able to locate the segments in the head region which consists of at least five primitive segments, while three are present in the thorax and eleven in the abdomen. There is an exoskeleton of chitin as in crayfish, although it is more flexible. Insects when first hatched frequently do not resemble the adult until they have passed through a change known as metamorphosis.

THE HONEY BEE.¹

The honey bee is suggested as the form to be studied in the laboratory. But for those who prefer the grasshopper, the text of the bee will serve for comparison.

There are nineteen general orders (see page 302) of insects, and the one regarded as the highest, the Hymenoptera, is the one to which bees, wasps, ants and ichneumon-flies belong. Many students of animals regard the body of these insects as being more highly

¹ Students are urged to read "The Life of the Bee," by Maeterlinck in connection with their study.

specialized than the body of the frog, bird or even man. This is particularly true of the ant.

Kinds.—There is but one species of the honey bee, *Apis mellifica*, which is the same whether found in a hollow tree far from human habitation or in an apiary near a large city. Bees are not domesticated like the horse, but retain all of their natural instincts. The honey bee was introduced into the United States as early as 1638. Bee-keepers recognize several subspecies or races of the honey bee, such as "Italian," "German," "Caucasian," etc.

The Honey Bee Colony.—A colony of bees is the general expression used among bee-keepers, but in attempting to describe scientifically the social habits of animals the term colony is restricted to such



FIG. 128.—The honey bee: a, worker; b, queen; c, drone. Twice natural size. (Phillips, United States Department of Agriculture.)

groups of animals as have an actual structural union like the hydroids (Fig. 105, a). In place of the word colony, biologists employ the term community to describe the varied and interesting life of the higher insects: bees, wasps and ants (see page 206).

The bee colony consists of three individuals, a single queen, many drones and thousands of workers (Fig. 128).

The Queen.—The single queen in each colony is the largest of the three. Her contribution to the welfare of the colony is the laying of the eggs from which young queens, drones and workers develop. "The number of eggs laid by the queen varies from a few daily, in early spring and late fall in the northern regions, to about 1500 to 2000 a day at the height of the egg-laying season. Under special conditions, usually artificially produced by the bee-keeper, she may

lay as many as 4500 or 5000 eggs a day and maintain this rate for several days. *The weight of the maximum number that can be laid in a day is equal to about twice the weight of the queen at any time during the period, indicating a marvelous rapidity in metabolism.*" The life of the queen is three or four years in length, with a few cases on record of seven years.

Drones.—These are the male bees, and it seems strange that there should have developed a social organism with but one female and several hundred males, as is shown by the bees. The usual social unit of one male and one female thus becomes highly modified in the bee colony. Compare these relations with those that exist in the seal (page 206).

A single drone mates with the queen but once in the life of the queen. As a result of this act the drone dies. The remaining drones in the colony are heavy eaters and contribute nothing to the welfare of the colony unless the old queen dies and a virgin is hatched or introduced into the colony. In this case she must mate before she can lay eggs. When the food in the colony becomes scarce there is reason to believe that the drones are first starved and then removed from the hive by the workers.

Workers.—The workers are females with their sex organs undeveloped. "They are justly called worker bees. These bees feed the growing larvæ; clean, guard and ventilate the hive; build comb, gather nectar, pollen, water and propolis, and, in fact, do all the work of the hive, except that normally they lay no eggs."

The length of time that workers live varies with the season. During the active period of summer, six weeks is long enough for them to become old, and frayed-winged individuals are commonly seen dead outside of the hive. Workers hatched in the fall live until the spring brood of workers is ready to care for the colony.

Structure of the Honey Bee.—The bee is like a specialized crayfish in its general body plan. There are the same jointed appendages (Fig. 126), with the addition of wings; there is an exoskeleton hardened by chitin and a grouping of the somites into the three body regions, head, thorax and abdomen.

Internally similar organ systems are present, the details of which belong to laboratory study. However, three special features are presented because they are of great importance in understanding bees. These are their manner of respiration, of reproduction and the making of honey.

Respiration.—The method of respiration in the honey bee introduces us to a plan entirely distinct from the use of the gills of the crayfish or the lungs of the frog. In Fig. 129 is shown part of the tracheal air tubes and sacs in the body of the bee. These are connected with the surface of the body at definite places and the opening through the exoskeleton is called a spiracle. These spiracles admit fresh air and permit the contained air to escape through the action of the muscles of the body. The tracheal air tubes ramify throughout the body, even penetrating into the brain. By this means oxygen is carried to all of the cells of the body.

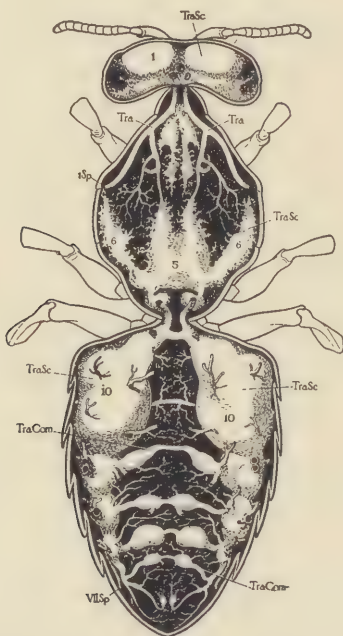


FIG. 129.—Tracheal system of worker, showing lateral and ventral parts as seen from above, with dorsal sacs and trunks removed in both thorax and abdomen. *Tra.* trachea; *TraSc*, tracheal sac; *TraCom*, tracheal commissure; *ISp*, first spiracle; *VII Sp*, seventh spiracle. (Snodgrass, United States Department of Agriculture.)

The tracheal system of air tubes in the bee is an illustration of the respiratory structures present in the body of all insects. Each order of insects exhibits modifications in the arrangement of the tracheal system, but the method of furnishing air to the cells is the same.

Reproduction.—The virgin queen takes her nuptial flight, during which she mates with a drone. In this act she receives spermatozoa which are stored in the sperm receptacle (Fig. 130, *Spm.*). The queen does not mate a second time, so that the sperms received constitute the only available supply during the entire egg-laying life of the queen, which is often four or five years. The sperms, then, remain alive in the sperm-receptacle of the queen, although they are “so highly specialized that they can take no nourishment.” It has been estimated that a single queen may lay 1,500,000 eggs, which would require that an enormous number of sperms be received at mating.

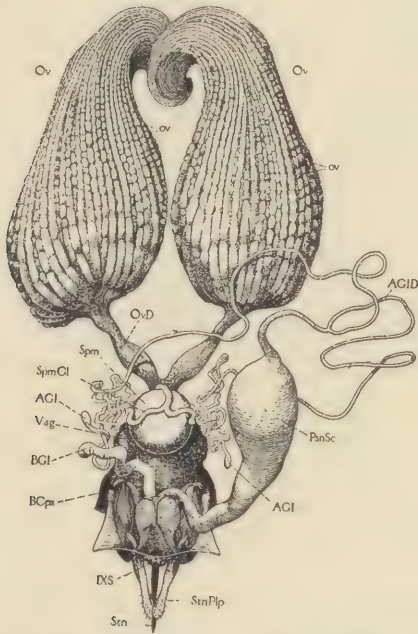


FIG. 130.—Reproductive organs, sting and poison glands of queen, dorsal view. *AGl*, acid gland of sting; *AGID*, duct of acid gland to sting; *BCpx*, bursa copulatrix; *BGl*, alkaline gland of sting; *Ov*, ovary; *OvD*, oviduct; *PsnSc*, poison sac of sting; *Spm*, spermatheca; *SpmGl*, spermathecal gland; *Stn*, sting; *StnPlp*, palpus-like appendages of the sting; *Vag*, vagina. (Snodgrass, United States Department of Agriculture.)

The eggs that hatch into queens or workers are fertilized and those that produce drones are unfertilized. By far the greater number of eggs laid by the queen are fertilized, for the workers greatly outnumber the drones. It is difficult to explain how the queen can lay both fertilized and unfertilized eggs. If it be an instinct, then it

is a most highly specialized one, for the even composition of the colony is maintained from year to year even when a new queen from a different race is introduced into the hive.

The method by which drones are produced is termed *parthenogenesis* or *asexual reproduction*. This is common among the insects. Parthenogenesis should not be confused with fission in paramecia or budding in hydra, for the drones develop from an egg that is just like all of the other eggs except that it is not fertilized.

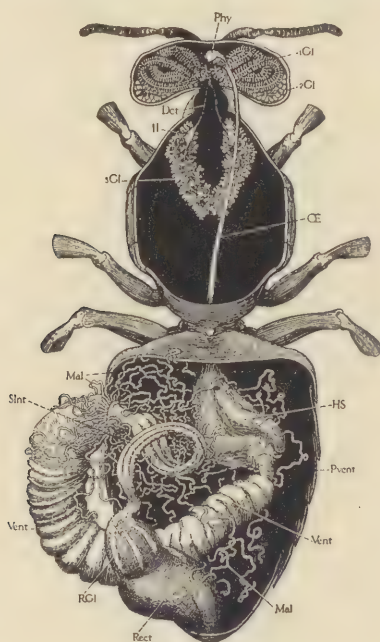


FIG. 131. — Alimentary canal of worker (*Phy-Rect*), together with pharyngeal glands (*1Gl*) and salivary glands of head (*2Gl*) and of thorax (*3Gl*), as seen by cutting body open from above and pulling the ventriculus (*Vent*) out to left. *Dct*, duct; *1Gl*, large pharyngeal gland in anterior part of head; *2Gl*, salivary gland in head; *3Gl*, thoracic salivary gland; *HS*, honey stomach; *Mal*, Malpighian tubules; *OE*, esophagus; *Phy*, pharynx; *Pvent*, proventriculus; *Rect.*, rectum; *RGl*, rectal glands; *Sint*, small intestine; *Vent*, ventriculus. (Snodgrass, United States Department of Agriculture.)

Honey.—The annual crop of honey in the United States alone is estimated to be worth about \$17,000,000 as food for man. Man has been eating honey since ancient times and critically studying all phases of the life of the bee for the past forty years. But as yet he can describe in only a general way how the bee makes honey.

The collecting of honey is done entirely by the workers, who suck the nectar from plants. This they swallow and store in the honey stomach (Fig. 131, *HS*), until they return to the hive, when it is deposited in a cell in the honey comb. "Here it is ripened into honey. This ripening consists in the removal of the surplus moisture, the water in honey usually being about 20 per cent. of the total, while nectar is often over 60 per cent. water. The chemical composition of nectars has not been sufficiently studied, and, indeed,

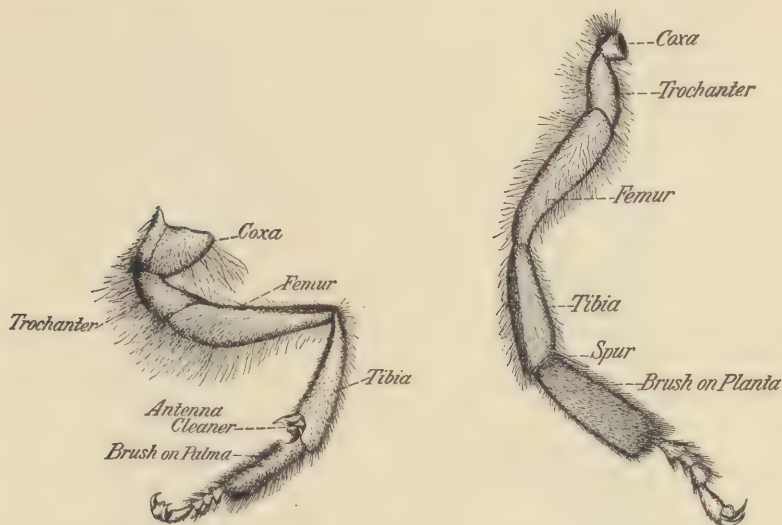


FIG. 132.—Left foreleg of a worker bee. (Casteel, United States Department of Agriculture.)

FIG. 133.—Left middle leg of a worker bee. (Casteel, United States Department of Agriculture.)

this is a hard problem, because of the difficulty of obtaining sufficient quantities without modification. Enough is known, however, to allow the assumption that the ripening process also includes the changing of sucrose (cane sugar) into invert sugars (dextrose and levulose)."

Pollen Collecting.—Closely associated with the gathering of nectar is the work in collecting pollen. This introduces one to a highly specialized series of instincts that should be compared to the special responses of the frog as illustrated on page 66.

The three pairs of legs and the hairs on the body and legs are the main structures that need to be considered. Figs. 132–136 show the legs and their hairs. The tibia of the last pair of legs is especially

modified to hold pollen, and the term pollen-basket or corbícula is given to this region.

"A very complete knowledge of the pollen-gathering behavior of the worker honey bee may be obtained by a study of the actions of bees which are working upon a plant which yields pollen in abundance. Sweet corn is an ideal plant for this purpose, and it will be used as a basis for the description which follows.

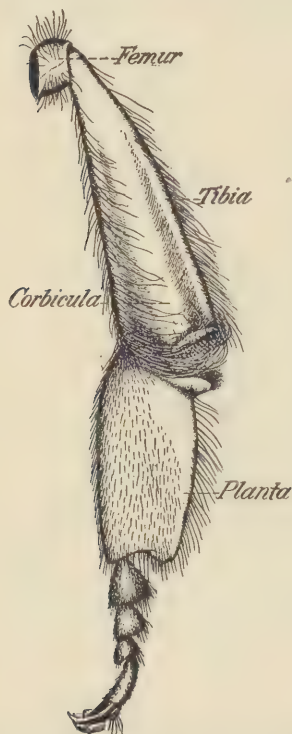


FIG. 134.—Outer surface of the left hind leg of a worker bee. (Casteel, United States Department of Agriculture.)

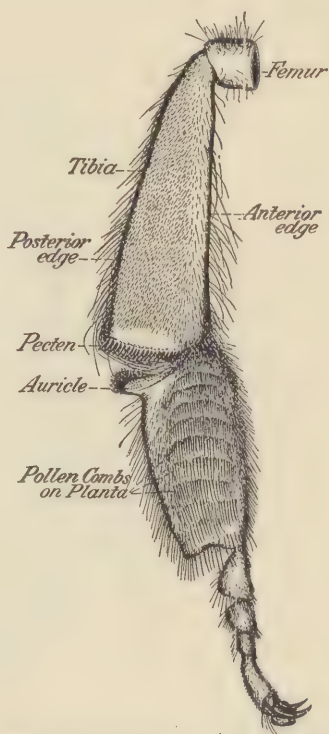


FIG. 135.—Inner surface of the left hind leg of a worker bee. (Casteel, United States Department of Agriculture.)

"In attempting to outline the method by which pollen is manipulated the writer wishes it to be understood that he is recounting that which he has seen and that the description is not necessarily complete, although he is of the opinion that it is very nearly so. The movements of the legs and of the mouth parts are so rapid and so many members are in action at once that it is impossible for the eye to follow all at the same time. However, long-continued observation,

assisted by the study of instantaneous photographs, gives confidence that the statements recorded are accurate, although some movement may have escaped notice.

“To obtain pollen from corn the bee must find a tassel in the right stage of ripeness, with flowers open and stamens hanging from them. The bee alights upon a spike and crawls along it, clinging to the pendent anthers. It crawls over the anthers, going from one flower to another along the spike, being all the while busily engaged in the task of obtaining pollen. This reaches its body in several ways.

“As the bee moves over the anthers it uses its mandibles and tongue, biting the anthers and licking them and securing a considerable amount of pollen upon these parts. This pollen becomes moist and sticky, since it is mingled with fluid from the mouth. A considerable amount of pollen is dislodged from the anthers as the bee moves over them. All of the legs receive a supply of this free pollen and much adheres to the hairs which cover the body, more particularly to those upon the ventral surface. This free pollen is dry and powdery and is very different in appearance from the moist pollen masses with which the bee returns to the hive. Before the return journey this pollen must be transferred to baskets and securely packed in them.

“After the bee has traversed a few flowers along the spike and has become well supplied with free pollen it begins to collect it from its body, head and forward appendages and to transfer it to the posterior pair of legs. This may be accomplished while the bee is resting upon the flower or while it is hovering in the air before seeking additional pollen. It is probably more thoroughly and rapidly accomplished while the bee is in the air, since all of the legs are then free to function in the gathering process.

“If the collecting bee is seized with forceps and examined after it has crawled over the stamens of a few flowers of the corn its legs and the ventral surface of its body are found to be thickly powdered over with pollen. If the bee hovers in the air for a few moments and is then examined very little pollen is found upon the body or upon the legs, except the masses within the pollen-baskets. While in the air it has accomplished the work of collecting some of the scattered grains and of storing them in the baskets while others have been brushed from the body. In attempting to describe the movements by which this result is accomplished it will be best first to sketch briefly the roles of the three pairs of legs. They are as follows:

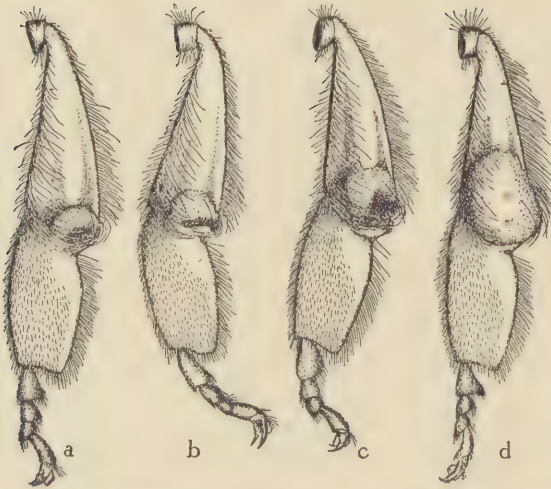


FIG. 136.—Camera drawings of the left hind legs of worker bees to show the manner in which pollen enters the basket. *a* shows a leg taken from a bee which is just beginning to collect. It had crawled over a few flowers and had flown in the air about five seconds at the time of capture. The pollen mass lies at the entrance of the baskets, covering over the fine hairs which lie along this margin and the seven or eight short stiff spines which spring from the floor of the corbicula immediately above its lower edge. As yet the pollen has not come in contact with the one long hair which rises from the floor and arches over the entrance. The planta is extended, thus lowering the auricle. *b* represents a slightly later stage, showing the increase of pollen. The planta is flexed, raising the auricle. The hairs which extend outward and upward from the lateral edge of the auricle press upon the lower and outer surface of the small pollen mass, retaining it and guiding it upward into the basket. *c*, *d*, represent slightly later stages in the successive processes by which additional pollen enters the basket. (Casteel, United States Department of Agriculture.)



FIG. 137.—A bee upon the wing, showing the position of the middle legs when they touch and pat down the pollen masses. A very slight amount of pollen reaches the corbiculae through this movement. (Casteel, United States Department of Agriculture.)

“(a) The first pair of legs remove the scattered pollen from the head and the region of the neck, and the pollen that has been moistened by fluid substances from the mouth.

“(b) The second pair of legs remove scattered pollen from the thorax, more particularly from the ventral region, and they receive the pollen that has been collected by the first pair of legs.

“(c) The third pair of legs collect a little of the scattered pollen from the abdomen and they receive pollen that has been collected by the second pair. Nearly all of this pollen is collected by the pollen combs of the hind legs and is transferred from the combs to the pollen-baskets.”

The details connected with the activities of the mouth parts and the detailed action of each pair of legs illustrate a very complex series of reflexes that help one to understand why the bee is regarded as such a highly specialized animal. This account of the honey bee has been taken from the following:

REFERENCES.

CASTEEL: The Behavior of the Honey Bee in Pollen Collecting, Bureau of Entomology, Bulletin No. 121.

PHILLIPS: Beekeeping.

SNODGRASS: The Anatomy of the Honey Bee, Bureau of Entomology, Technical Series No. 18.

PART IV.

SOME BIOLOGICAL ADAPTATIONS.

CHAPTER XIX.

PARASITISM—GREGARIOUSNESS.

Adaptation.—It is so difficult to mark off sharply the habits of organisms that it seems wise to describe some of the general conditions of adaptation. Each organism is limited in size and occupies a definite place in nature. The mere fact that this statement can be made implies that each organism is fitted to live in the place where it is found. Here surrounded for the most part by inanimate particles it lives its life. In one sense all nature constitutes its environment, but in a more restricted sense its immediate surroundings most deeply affect the various parts of the organism.

Animals and plants are adapted to living in the water, on land, at sea level, on the mountain top, in the tropics, in the Arctic circle, in the hot springs of California and the Yellowstone National Park—in short, everywhere on our globe. But when man attempts to transfer plants and animals from one environment to another then the extent of adaptation is appreciated. Most organisms become so thoroughly adapted that they cannot be transferred; the polar bear cannot live in the tropics for any length of time, and the palms of the South die in the North unless housed. Examples could be indefinitely multiplied.

One must keep in mind that each organism begins life in a single cell and that each organ as it assumes its work in the body of the organism gradually acquires certain physiological ways of working that add to the success of the whole organism, with the result that adaptation is really a problem that must go to the protoplasm for its final analysis. Besides the changes involved in day and night, in temperate regions there is the seasonal adaptation, conspicuously

illustrated in winter when leaves are shed and birds migrate to warmer climates. The habits of each group of animals indicate that some prefer the night time for foraging while others do best during the day. At the bottom of all of these varied and numerous adaptations are specific differentiations in cell structure or cell physiology.

With the diversified physiographic conditions that obtain on the globe it is to be expected that organisms will have developed many unusual methods of gaining a livelihood. The profligacy of Nature in producing such vast numbers of individuals has resulted in her constantly turning loose more individuals than can find a foothold.



FIG. 138.—The bed-bug (*Cimex lectularius*). *a*, adult female gorged with blood; *b*, the same from below; *c*, rudimentary wing pad; *d*, mouth parts. *a* and *b*, much enlarged; *c* and *d*, highly magnified. (Marlatt.) Relapsing fever and kala azar are carried by the bed-bug. (Rosenau.)

The struggle for food is the most satisfactory explanation for the origin of some of these peculiar habits. Cooperation began in nature with the first pair of animals. This pairing springs from a universal necessity for all of the higher animals, namely, to ensure the perpetuation of the species; for this the united energies of the two are required, especially where parental care exists. This means that the individual is not the social unit but that two animals that have paired either temporarily or permanently constitute the unit. In those animals that exercise no care of their young there is usually an enormous drain on the parents in producing a large number of eggs and sperms which compensates in part for the lack of parental care. The necessity of having a place to live, whether it is temporary

or lasting, implies ownership of that place for the time being; with some animals this simply means a limited occupancy, while with others possession is exclusive. The social unit, the pair, prevails in all classes of animals above the protozoa; and as the scale of complexity is ascended it becomes more predominant.

Under conditions which are but partly understood both animals and plants become adapted to live in relationships quite distinct from these just described. Such special terms as parasitism, symbiosis and community life are commonly used to describe these acquired adaptations. The following is but a brief outline of some of their habits, and the student is urged to read in addition Van Beneden's *Animal Parasites and Messmates* and Jordan and Kellogg's *Evolution and Animal Life*, Chapters XVI to XIX.

PARASITISM.

The term "parasitism" was first employed to describe those who sat around the tables of the rich in ancient Greece receiving their invitation through fawning and flattery. When the word was used to describe a similar relation among animals it was applied to animals that have taken to a thievish existence as unbidden guests in or on other organisms. Our knowledge of the facts of parasitism goes back into the sanitary codes of the Jews and Egyptians which declared as unclean such animals as the pig, rabbit and dog, animals now known to be especially infested with parasites, and it is only within recent years that our sanitary laws have made pork a clean meat. During the middle ages the school men perplexed themselves with quaint hypotheses as to the time and place of the introduction of parasites into man. The idea that life could spring suddenly into existence was a fruitful suggestion for their origin, and it was not until the eighteenth century, when the life-history of one of the flesh-eating flies was completely worked out, that scientific men began to suggest that parasites arose from free-living animals. This discovery led to a truer knowledge of the origin of parasites, and from then on until today there is not a parasite known that cannot be traced in origin to some antecedent life.

Classification of Parasites.—Biologists would be glad if they could work out an exact classification for the plants and animals that lead a parasitic life, but this is impracticable because the adaptations that have taken place do not follow any regular law, as the following shows: Animals like horse-flies and mosquitoes, which

come and go, may be termed *temporary*; while the bird-lice which pass their entire life on the bird are called *permanent*. The fleas, ticks, dodders, mistletoes and others confine their relation to the

outside of their host, and the term *external* is applied; while the tape-worm of cat, dog or man is entirely within the body, and so should be called *internal*. This life history affords another method of classification. The leech is parasitic in the *adult* while the larva of the fresh-water clam always passes a part of its development encysted in the gills of some fish, typifying a class of animals parasitic only during their *larval* existence. From this same standpoint there are those animals also which either *complete* their *life* in *one host*, such as the pup worms found in young seals, or those that demand *several* hosts. Of this latter class is the organism malaria, which spends part of its life in the blood of man and the remainder in the body of the anopheles mosquito. Or the malarial parasite may be classified as one that is dependent for its existence upon its hosts and thus termed an *obligatory* parasite; while any parasite which temporarily lives within or upon a host and can exist without utilizing the parasitic habit a part of the time is called a *facultative* parasite. The para-

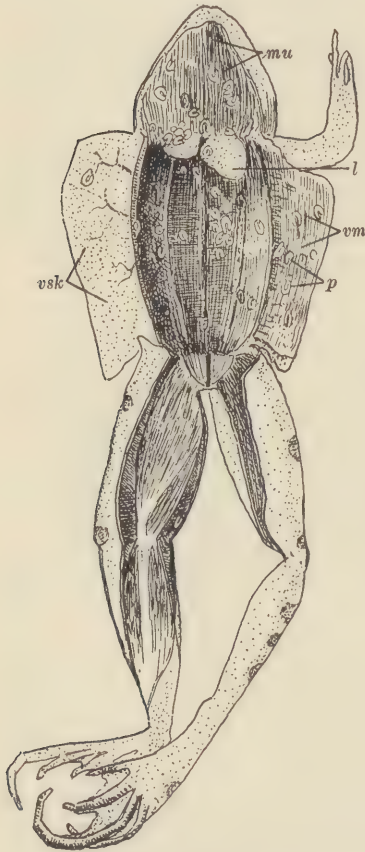


FIG. 139.—View of the ventral surface of the frog after the removal of the coelomic viscera, showing numerous encysted flukes. *l*, lung; *mu*, muscles of floor of mouth; *p*, flukes in place; *vm*, ventral muscles of coelomic cavity; *vsk*, skin of ventral coelomic wall. (Osborn.)

sitic bacteria belong in the main under this latter term. The effect on the parasite affords still another form of classification. Some parasites, like the leech, mosquito or trichinella, show very little effect as a result of this habit; while the great majority are

permanently and noticeably degenerated as a result of their mode of living. The most important aspect of this question is the effect of parasitism, first upon the parasite and then on the host. As a general

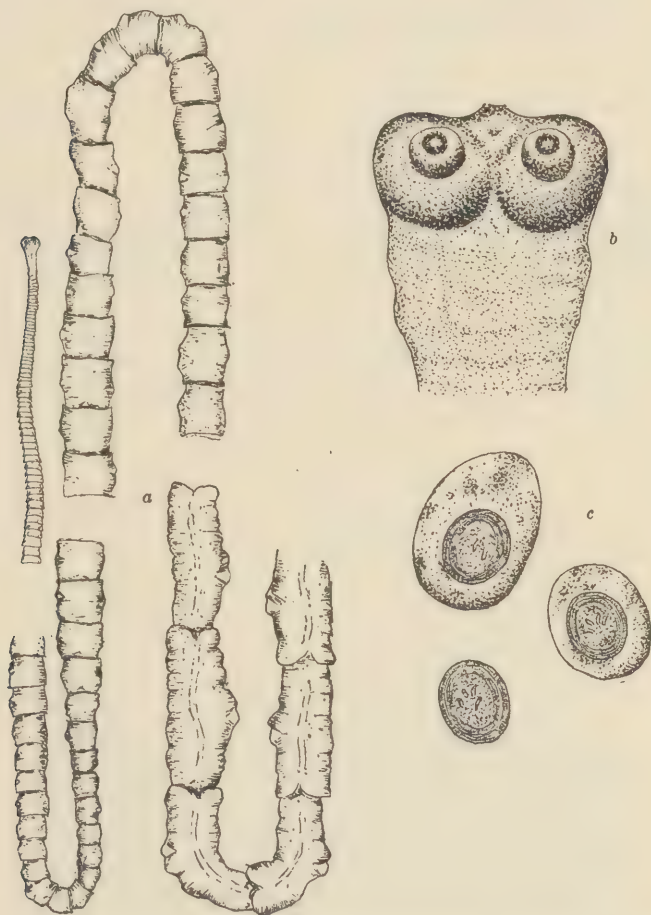


FIG. 140.—*Tenia saginata*. a, natural size; b, much enlarged; c, ova much enlarged. (Simon.)

statement the parasitic habit tends to weaken the self-dependence of the parasites. This is shown in many ways other than the inability of the parasite to live alone and thrive. Some of the parts of the body actually disappear, although present in the young animal. The marine crab is infested with a conspicuous example known as

Sacculina. This parasite has a complete set of all the organ systems characteristic of its class while it leads a free-swimming life, but as soon as it becomes parasitic its appendages, food canal, sense organs and nervous system are lost, the body consisting essentially of reproductive tissue, a system which never degenerates. The tape-worm has no alimentary canal and only the remains of a nervous system. Other examples could be given to show that there is an actual loss of organs that the parasites need when living alone. The parasite loses these parts because it has no use for them; thus failure to use an organ tends to its obliteration.

Extent of Parasitism.—It is a well-known fact that all of the larger animals harbor or may harbor many parasites, but as soon as careful studies are made the smaller animals also are found to be parasitized, even to the protozoa. One recent expert says that "it is not a too sweeping generalization to state that every living thing large enough to contain another living thing is subject to invasion by parasites. The protozoa, themselves single cells, often play the part of host to smaller protozoan cells, and parasites often infect the nucleus of ameba, paramecium, vorticella and other types." It is difficult to make the word parasite convey an exact meaning, for we know that many trees harbor hundreds of insects; that the fly, mosquito and others occasionally bite us. From the fly to the tick is but a short step, and the tick is surely a parasite. The sheep in the pasture feeding upon the grass and the fox killing mice for her young are in a broad sense living on other living things. These cases are not regarded as parasitism, although the habit is essentially the same. The word parasite is best limited to such plants and animals as literally take up their residence for a time upon some other form of life, which is the host. This means that the parasite is always smaller than the host, although it may be a higher organism. In most instances parasites are simpler in structure than their host, as the tape-worm in dog or the ameba in man.

Parasitic Habits.—It is impossible in the limits of this book to do more than illustrate the most conspicuous habits of parasitic organisms. Parasites that are parasitic in the *larval stage only* are well illustrated by the habits of the fresh-water clams. When the embryos of these clams have passed through the segmentation stages they grow into a form known as the *glochidium* (Fig. 141). This is a stage in the development of the clam quite unlike the adult. It bears the same relation to the clam that the tadpole does to the frog. When the glochidia are set free in the water they sink to

the bottom. They are entirely incapable of locomotion, although the adductor muscle causes the valves to close frequently, and in response to mechanical stimuli the valves close firmly and remain closed. As the fins of a fish brush over the hooked glochidia they become attached to the fish. Here they remain as parasites from two to



FIG. 141.—Axe-head glochidium of the clam, *Lampsilis* (*Protera alata*), anterior end view. In the larval stage the glochidium of certain fresh-water molluscs lives from nine to thirty-six days as a parasite in fish, and this is a necessary stage in its life history. (Le Fevre and Curtis.)

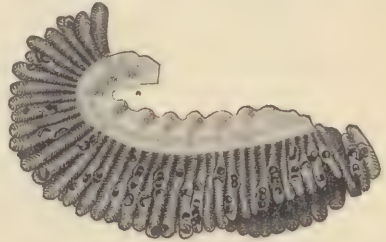


FIG. 142.—Gill of yellow perch infected with glochidia of the clam (*Lampsilis ligamentina*), showing distribution upon the gill as a whole and the appearance of the cysts. They are also found on the fins. (Le Fevre and Curtis.)

ten weeks, the length of time depending upon the species of clam. The glochidia which do not have hooks become attached to the gills (Fig. 142), entering through the mouth of the fish as water is taken in for respiration. During the time that the glochidia remain as parasites on the fish they are metamorphosed into small clams. Unless the glochidia become attached to the fish they die.¹ A mod-



FIG. 143.—Second larval stage of "horse-hair" worm in body of grasshopper.

erate-sized fish may carry successfully from one to two thousand of these parasitic glochidia. The fresh-water clams of several species thus illustrate a specialized habit in which fish have become necessary to the clam's growth to maturity.

¹ Le Fevre and Curtis: Studies on the Reproduction and Artificial Propagation of Fresh-water Mussels, Bull. Bureau Fisheries, 1910, xxx, Document No. 756.

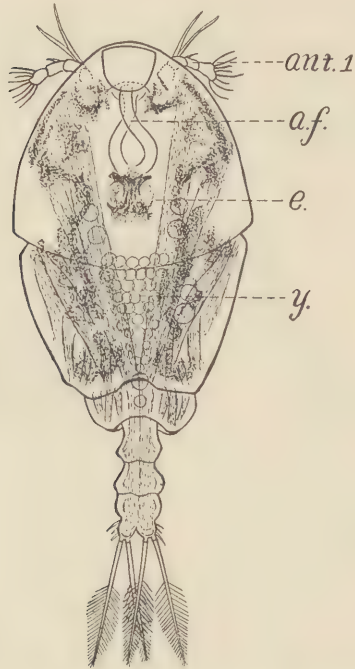


FIG. 144.—*Salminicola edwardsii*. Dorsal view, free-swimming stage. $\times 173.5$. a.f., attachment filament; ant. 1, first antennæ; e, x-shaped eye; y, yolk. (Fasten, Journal of Animal Behavior.)



FIG. 145.—Adult fish-louse, *Salminicola edwardsii*. Compare the structures present with those in Fig. 142. (Redrawn from C. B. Wilson.)



FIG. 146.—“Fish-lice” attached to gill of fish.

A similar parasitic habit is evident in the "horse-hair" worm shown in the body of the grasshopper (Fig. 143). These worms are not parasitic when adult and are commonly seen in springs, watering troughs, etc. The eggs hatch into a small larval stage that usually enters the body of some insect. After passing through certain changes it is set free in the water. This condition is known as the second larval stage. The second larval stage enters the body of an insect or fish, where it continues to live until it comes to look much like the adult worm; but before the adult stage is reached this second larval stage leaves the body of its host and becomes a free-swimming worm in the water. Here it quickly reaches sexual maturity and is able to set free eggs, thus completing the life cycle. The worm shown in the body of the grasshopper is the second larval stage of the "horse-hair" worm.

A group of parasites familiarly known as "fish-lice" are widely distributed among both salt- and fresh-water fish. There are 136 different species, all of which are parasitic during their *adult life only*. The species *Salminicola edwardsii* is very common, although found exclusively on the brook trout. It lives attached to the fins and gills of the fish (Fig. 146). In its adult stage the female undergoes a great deal of degeneration (Fig. 145). During the larval stage the young animal swims actively about and possesses the usual organs found in the group of crustacean animals to which it belongs (Fig. 144). The specialized habits of the "fish-lice" are the reverse of the clam and the "horse-hair" worms, but the fish has come to be just as necessary to the fish-lice as it is to the clam. These two parasites also illustrate the effect of parasitism upon the parasite, for the worms show practically no change, while the fish-lice undergo a large amount of degeneration.

The following study presents a phase of parasitism that is very important not only because it illustrates the *complicated life history* of certain parasites, but also because it indicates how difficult it is to prevent the spread of such parasites.

White Pine Blister Rust.¹—The organism which causes the white-pine blister rust lives in one stage upon the pine and in the other on the leaves of currant or gooseberry bushes. It is a plant that belongs to the fungus group known by the technical name of *Cronartium ribicola*. Like most fungous plants there are produced spores which are carried by the wind. When the spores of a certain stage

¹ Perley Spaulding: The White-Pine Blister Rust, Farmers' Bulletin, No. 742.

in the life of this parasite fall upon the white pine they begin to grow in the bark. Here they may live from one to six years with



FIG. 147.—Diagram indicating the life circuit of the causal fungus of the white pine blister rust. *a*, blisters on pine in May and early June, from which the disease spreads to currant or gooseberry leaves and produces the early summer stage, *b*, thence it may spread to another currant leaf and produce there a second crop of the early summer stage, *c*, or it may produce the late summer stage, *d*, in this stage; in the fall it infects neighboring white pines, which may or may not include the pine (*a*) which bore the blisters that started the outbreak the preceding spring. (Spaulding United States Department of Agriculture.)

no external sign of their presence. The first indication of the presence of these parasites is the swelling of the bark at the point of infection. Fruiting bodies push their way through the swollen tissue. As these ripen numerous spores like bright yellow powder are discharged. Each spore is capable of reproducing the disease but they cannot grow upon the white pine. To distinguish these spores from a second kind of spore they are called peridermium spores (Fig. 147).

The peridermium spores are blown about by the wind, and if one falls upon the leaf of a currant or gooseberry plant it is able to attack that leaf. This small spore "sends its root-like germ tube into the soft tissues of the currant leaf, and there it spreads within the leaf tissues until it has attained a certain amount of strength." In about two weeks there appear on the upper side of the currant leaf tiny masses, hardly larger than a pin-head, of fine, orange-yellow powder. These new spores are quite distinct from the peridermium spores and hence are called uredospores.

The uredospores may be called the repeating stage, as these spores can only reinfect currant or gooseberry leaves. This they may go on doing every two weeks from the latter part of July until the leaves drop off in the fall. At this time a third form of spore is grown which appears in the same spots that have been earlier producing uredospores. "The new form appears as a group of three to ten of short, stout threads, not over a quarter of an inch in length, and usually are in small circles. Upon these threads are produced spores of another distinct form. These are the teliospores."

The teliospores cannot repeat their development on the currant or gooseberry leaves but must fall upon the bark of young white pines. These spores now can germinate, penetrate the bark and grow in the inner layers. The life cycle is complete. The presence of numerous wild currant bushes in forests of white pine is a source of real danger.

The white pine blister rust illustrates what is known as the alternation of hosts in the life cycle of parasites, which should not be confused with alternation seven generations in hydroids, for example, page 150.

Why are Parasites Sometimes Very Numerous?—The student will find an answer to his question, "Why are parasites more numerous in certain parts of the country or during certain years?" in the following explanation of the life history of the spring grain aphid. In order to answer this question accurately it is necessary to know

in detail the habits of the animal about which the question is asked. The explanation, however, is to be found in the relation which certain conditions, such as food, temperature, time of breeding and enemies, bear to each other. The following, then, is a typical scientific explanation of the abundance or scarcity of parasites. "The spring grain aphid (*Toxoptera graminum*) is present every year in greater or less abundance and is kept under control by its natural enemies, more especially by a tiny black and brownish four-winged fly (*Lysiplebus tritici*). The aphid gives birth to young from spring to fall, but during mild winter weather young are born as long as such weather continues while the parasite remains dormant. The aphid begins to breed whenever the temperature rises to 45° or 50° F. during the day, while for the parasite it must be at least 10° warmer. Under normal weather conditions during winter and spring the aphid starts in the spring from the eggs (winter eggs), and there are enough parasites which have wintered over in the bodies of the aphid and emerged therefrom to destroy so many of this aphid that it cannot increase rapidly enough to become injurious; consequently there is no trouble. But there comes a winter during which the temperature is warm enough to enable the aphid to breed continuously, and it thus becomes abundant by spring. If the weather turns cold during the winter the pest ceases to breed and serious depredations are averted; but if, as is more often the case, a cold, backward spring follows an abnormally warm winter then the pest continues to breed while its enemies remain inactive, and the result is that the former becomes so enormously abundant that wheat and oats are destroyed over large sections of the country before the parasite can increase sufficiently to overcome it." (Webster.)

Symbiosis.—There is another set of relations where two dissimilar organisms live together for their mutual benefit, which is conveniently described by the term symbiosis, and simply means a living together. These relations occur between animal and plant, animal and animal and plant and plant. For example the lichen is a simple grayish plant growing on fences, stones, etc. If a botanist is asked to classify the lichen he usually hesitates, because the plant consists really of two distinct plants that have become so intimately associated that neither lives alone. The grayish color is due to the effect of the whitish fungi which grow over and around some green cells. The fungous elements belong to the same class of plants as the mushrooms, while the green cells are intimately related to the plant that often gives a greenish tint to the bark of trees (Fig. 75, A)

and to the plants growing in ponds, and known as pond scum. These two distinct plants live intimately associated, and it is difficult to see how the relation is harmful to either, and, 'in fact, it is regarded as decidedly beneficial. The second example is where two animals live together. The hermit crab, a form related to the lobster, protects itself by occupying empty snail shells, into which it backs in case of danger (Fig. 148). In the Mediterranean Sea there is frequently found on such a snail shell a large sea anemone which is permanently attached to it. The sea anemone belongs with the corals, jelly-fish and hydras—a much simpler and lower class of animals than the crabs. The sea anemones are provided with



FIG. 148.—Hermit crab occupying a fossil snail shell. The surface of the snail shell is mostly covered by the incrustations of numerous small tube-forming worms. These hermit crabs live in holes near the water on the Bermuda Islands. To this species of hermit crab this fossil snail shell is but a convenient and safe retreat and serves the same purpose that the shell of a present-day snail would if available.

numerous stinging organs that have a paralyzing effect which renders them inedible. Now the hermit crab is eaten by predaceous fish, but not when it carries the sea anemone around on its back. The sea anemone gathers its food from the water, but it is stationary in habit and can secure only what the water brings to it. The hermit crab moves about from place to place, thus enabling the sea anemone to secure food more easily. Such are some of the obvious reciprocal benefits.

Between true parasitism and real symbiosis there are very many social relations that cannot be properly described by either term, nor is there any sharp line of demarcation between them, but an indistinct gradation from one to the other. These symbiotic and

semisymbiotic relations are not very numerous in nature and are hard to explain when the benefits are not obvious (Fig. 149); in fact, some writers believe that all of these are parasitic relations. Degeneration does not appear to be a conspicuous part of the symbiotic relations. The motive for the habit seems to be greater protection and ease in gaining a livelihood. It is conceivable that some of the relations are of the same character as in human affairs where an individual is continually being assisted without returning the compliment. Certain barnacles have a habit of burrowing into the skin of whales; the barnacle gains all of its food from the water and is carried from place to place by the accommodating whale, which surely cannot be benefited in any way by these minute animals and apparently has no way of preventing the relation. It seems somewhat extreme to be always trying to figure out some utility for all of the

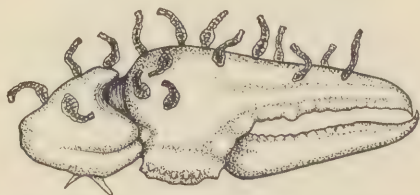


FIG. 149.—These small worms are found attached to the exoskeleton of the crayfish. They feed upon unicellular algae and diatoms, so do not derive any food from their host. In this instance these worms, *Branchiobdella pulcherrima* and *B. instabilia*, cannot be regarded as parasitic nor are they symbiotic in the usual meaning of this relationship. Drawn from material collected in Lake Clear, Adirondacks.

varied relations we observe. They may be regarded as some of Nature's partly successful experiments; at any rate, they are unusual and eccentric and are given here to show that there is a wide range of relations in the social life of animals.

Community Life.—The social life of the honey bee (page 182) is an illustration of this specialized social habit. A higher degree of community life is found among some of the ants, where, in addition to the sexless worker, there are to be found soldiers and slaves. An interesting account of the complicated family life of the ants is found in Chapters XIX to XXVII of Wheeler's book on Ants.

Gregariousness.—Among the birds and mammals the habit of forming flocks for all or part of the year is common. In some of the flocks a form of polygamy exists, the king of the flock killing the other males in combat. Such a collection of animals is obviously one



FIG. 150.—A harem on Gorbatch rookery; the bull with many cows and newborn pups, July, 1914. Each harem consists of a single bull and from 20 to 100 cows. (Parker.)



FIG. 151.—Murrets or arries on Walrus Island, July 16, 1914. (Osgood, Preble and Parker, Bulletin of the Bureau of Fisheries.)

in which protection against enemies is the dominant reason for the association (Figs. 150 and 151).

In this very brief survey of some of the adaptations of organisms, particularly animals in their several habits, the many structural adaptations and the whole question of color has intentionally been omitted because of lack of space. It is important to understand that these many relations represent acquired, though perfectly natural, habits that have reached their present high state of differentiation through a series of gradual adaptations. In seeking to explain the phenomena of parasitism and symbiosis the factors in the immediate environment are the causes to be studied. The community of the ant and bee has become so highly specialized that they could not exist if each individual pair were compelled to live apart; and the same is true of some of the parasites which live in two or more hosts, like the tape-worm or the rust: when one of the hosts fails the species is unable to perpetuate its kind. While, on the other hand, there are parasites that can live attached to a host for a time and equally well when separated from it. This is the case with many of the parasitic bacteria, which suggests that bacteria now non-parasitic may gain access to some animal and cause a disease new to science.

CHAPTER XX.

ADAPTATION AND DISEASE.

The Role of Biology.—To biology belongs the study of the several pathogenic organisms in their relation to other organisms, in their habits and in their life history. These several aspects of disease causing organisms reveal a phase of protoplasmic adaptation that is not gained from any other study in biology.

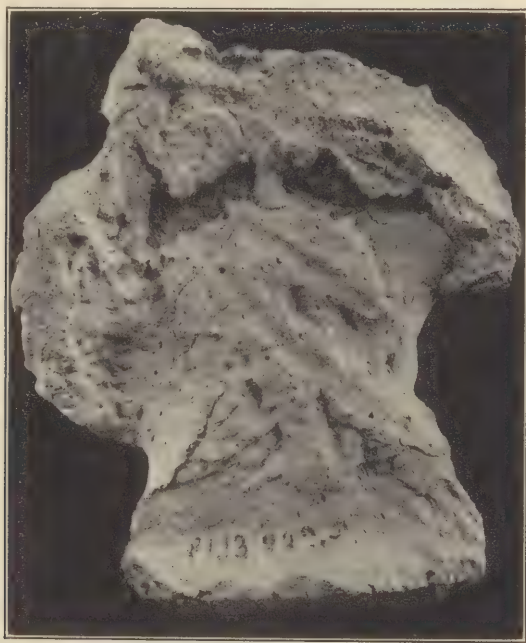


FIG. 152.—Photograph of the lateral aspect of a humerus from the fossil known as Mosasaur from the cretaceous rocks of Kansas. The diseased condition is known as osteoperiostitis. The disease is a condition that has existed in organisms from the earliest times. (Photograph furnished by Roy L. Moodie.)

The pathogenic organisms have a definite life history that must be understood in order to prevent their gaining access to plants, animals and man. It is important to recognize at the outset that

these biological diseases occur generally in Nature and often with disastrous results as the frequent epidemics in insects, in fishes, in trees, in potatoes, etc., indicate. Their manner of causing disease and all of its accompanying phenomena can be as well studied in plants as in animals. The knowledge that definite plants and animals cause disease is one of the most valuable facts in our modern civilization, for it supplies us with the exact information necessary to prevent disease. There is no way of measuring the money value¹ of a human life, and yet hundreds are dying daily in the world at large from these biological, preventable diseases. Every agency should be utilized in spreading accurate information about disease and its prevention. It is impracticable in the following sections to describe all of the biological diseases, hence certain typical ones are selected to illustrate the general principles involved. As these several examples are studied note (1) that in all instances the disease-producing agent is a normal and natural product to which the organism has become adapted; (2) that the seriousness of the disease and the problem of recovery is one phase of adaptation; (3) that the main purpose of this chapter is to help us understand the nature of living protoplasm. It is not a medical treatise on disease.

Rattlesnakes.—The rattlesnakes all possess a gland, located on both sides of the head and just below and behind the eye, which secretes a poison. From the anterior end of the poison gland extends a duct that opens at the base of the fang. The following account will serve to illustrate how the poison acts upon man: One of the attendants at the National Zoölogical Park was bitten, on August 17, by a diamond rattler (*Crotalus adamanteus*) on the middle finger of the left hand, proximal phalanx. The wound was immediately sucked and within fifteen minutes cauterized with a 1 per cent. solution of potassium permanganate. He was removed to a hospital where the following changes were found to be taking place: On admission the blood examination was: red blood cells, 4,600,000; white blood cells, 14,440; hemoglobin, 95 per cent. Eighteen hours after being bitten the blood examination was: red blood cells, 4,000,000; white blood cells, 16,000; hemoglobin, 75 per cent. On the fourth day the blood count was: red blood cells, 2,800,000; white blood cells, 14,000; hemoglobin, 60 per cent. The sixth day showed the lowest condition of the blood: red blood cells, 2,000,000;

1233

¹ Dr. A. R. Ward, of the Bureau of Animal Industry, estimates that the annual loss from diseases in cattle, sheep and hogs is \$212,000,000. Most of these diseases are preventable.

white blood cells, 12,000; hemoglobin, 45 per cent. After this date the patient began to recover and the cells of the blood gradually returned toward the normal, although six weeks after the snake had bitten him his blood count was only: red, 3,588,000; white, 9000; hemoglobin, 87 per cent.¹

This case serves to indicate that there is a direct relation between the loss of the red blood cells and the bite of the snake. When the rattlesnake venom is injected into the blood of other mammals a similar result obtains: The breaking down of the red blood cells (chromolysis) is only part of the process but serves to indicate the definite result that comes to certain cells of the body when they come in contact with rattlesnake venom. As is well known the bite is fatal in about 40 per cent. of the cases.

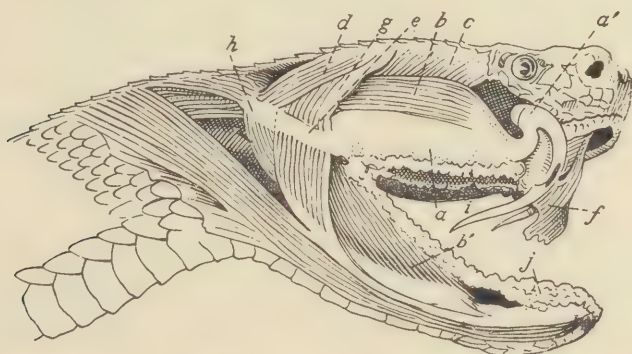


FIG. 153.—Poison apparatus of rattlesnake, venom gland and muscles. Lateral view. *a*, venom gland; *a'*, venom duct; *b*, anterior temporal muscle; *b'*, mandibular portion of same; *c*, posterior temporal muscle; *d*, digastric muscle; *e*, posterior ligament of gland; *f*, sheath of fang; *g*, middle temporal muscle; *h*, external pterygoid muscle; *i*, maxillary salivary gland; *j*, mandibular salivary gland. (From Steineger, after Duvernoy.)

When man is bitten by a cobra the sequence of the pathological changes are distinct and easily recognized. In addition to the destruction of a large number of red corpuscles the coagulating power of the blood is lost. Then follows a weakness in the legs and throat which soon develops into a paralysis of these parts. Finally the nervous centers that control breathing become involved and death occurs from respiratory paralysis.

¹ The details of the case are given by Dr. C. S. White in Jour. Am. Med. Assn., 1910, lii.

The following Carnegie publications are the best references to rattlesnakes:

NOGUCHI, HIDEYO: The Action of Snake Venom upon Cold-blooded Animals, Octavo, 16 pages. (Embodied in Publication No. 111.) Published 1904. Price \$0.25.

NOGUCHI, HIDEYO: Snake Venom: An Investigation of Venomous Snakes, with Special Reference to the Phenomena of Their Venoms. Octavo, xvii + 315 pages, 33 plates, 16 text figures. Published 1909.

Although this volume refers more especially to the phenomena of snake venom, it covers much broader ground. The first fifty pages are devoted to a descriptive and systematic morphological and a distributional account of the poisonous snakes of the world, over 300 forms being enumerated, followed by a description of the poison apparatus. In a short chapter on the phylogeny of poisonous snakes the author states that the poison was probably the first of the specialized structures to appear and that the elaborate, erectile, grooved fangs were of later development. The poison gland "is equivalent to, if not identical with, the parotid of the mammalia." The remainder of the work is given up to a consideration of the venom itself. There are chapters on its physical and chemical properties; symptoms of venom poisoning in man and in lower animals; and on the organism as a whole and upon specific organs and tissues, this latter subject being more fully treated than any other.

There follow chapters on artificial and natural immunity, with a technical discussion of antivenins. The final chapter, "Treatment of Snake Bites," contains a careful review of the various so-called antidotes, with a scientific testing of their value. The monograph ends with a bibliography of about 400 titles and an index.

LOEB, LEO, in collaboration with Carl L. Alsberg, Elizabeth Cooke, Ellen P. Corson-White, M. S. Fleisher, Henry Fox, T. S. Githens, Samuel Leopold, M. K. Meyers, M. E. Reh fuss, D. Rivas and Lucius Tuttle: The Venom of *Heloferma*. Octavo, vi + 244 pages, 38 figures. Published 1913. Price \$1.50.

This volume contains a collection of papers dealing with the morphology of the venom gland, the physical and chemical properties of the venom, the action of the venom on vertebrate and invertebrate animals as well as on certain cells and organs *in vitro*.

Amanita.—Every year there are cases of mushroom-poisoning which terminate fatally. In all of these serious cases the mushroom eaten is probably one of the amanita group. The general effect of the poison is to produce acute intestinal pains and a rise in the pulse and temperature, often accompanied by delirium. The following is taken from Ford's recent study of the poisons in fungi: "It has been shown that the 'white' or 'deadly' *Amanita phalloides* contains a powerful hemolysin which acts upon a great variety of corpuscles, is destroyed by heating to 60° to 65° C. for half an hour and has the chemical composition of a glucoside containing C = 48.03, H = 6.08, N = 10.83, S = 1.94, O = 32.22. This substance, judging from its destruction by heat and its susceptibility to the action of artificial gastric juice, cannot be held responsible for the symptoms seen in poisoning with the fungus in man. The species apparently owes its toxicity to the amanite toxin. Five cubic centimeters of the extract of *Amanita phalloides* killed a guinea-pig weighing 385 grams overnight, the same amount killed another guinea-pig weighing 420 grams in four hours and a rabbit weighing 1035 grams succumbed within eighteen hours to a dose of this character.

"The *Amanita muscaria*, known popularly as the 'yellow' or the

'fly' amanita, owes its toxicity to the crystalline substance, muscarin, an ammonia derivative with the following chemical composition: $C_5H_{15}NO_3$. The muscarin extracted from this plant acts upon the nerve centers and the animal dies in convulsions. In addition to the muscarin this species contains also a hemolysin and an agglutinin, the latter acting like a glucoside."

The poison of the rattlesnake and the toxin of amanita are complex substances and already analyzed into two or more parts, and each of the components is responsible for a definite set of changes when introduced into man. In both instances the product is a normal growth of the organism.

The secretion from the poison gland of the rattlesnake is a poison which is a relatively simple chemical molecule that is broken down by digestion. This is the reason that it is safe to suck the wound caused by a poisonous snake. On the other hand the toxin found in amanita is a complex chemical molecule that is not destroyed by digestion. In a general way this serves to distinguish between organic poisons and toxins.



FIG. 154.—*Amanita phalloides*.
(Rusby.)

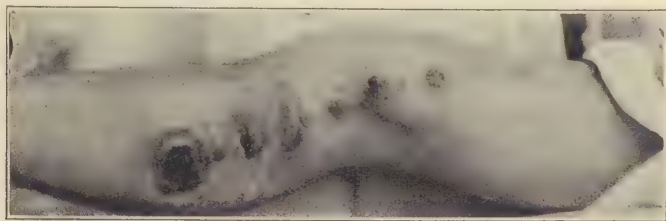


FIG. 155.—*Sporotrichosis*. Appearance of leg on entrance into hospital four months after initial lesion. (Hamburger.)

Sporotrichosis.—This is not a common disease in man, although the authentic number of cases has increased during the last few years. The disease is described here because it illustrates so well the relation of a definite organism to a specific pathogenic condition. Small ulcers occur usually on the leg and hand, and from these ulcers may

be cultivated a definite plant, as shown in Fig. 156. It grows exceedingly slowly when first cultivated in culture tubes. The growth of the second and third generations, however, is much faster. The organism consists of a branching mycelium with here and there spore-bearing branches. When cultures of the spores are injected into white rats and guinea-pigs abscesses form in some instances, and preparations from these abscesses show the presence of similar spores. In sections of the tissue similar spores are also found.¹

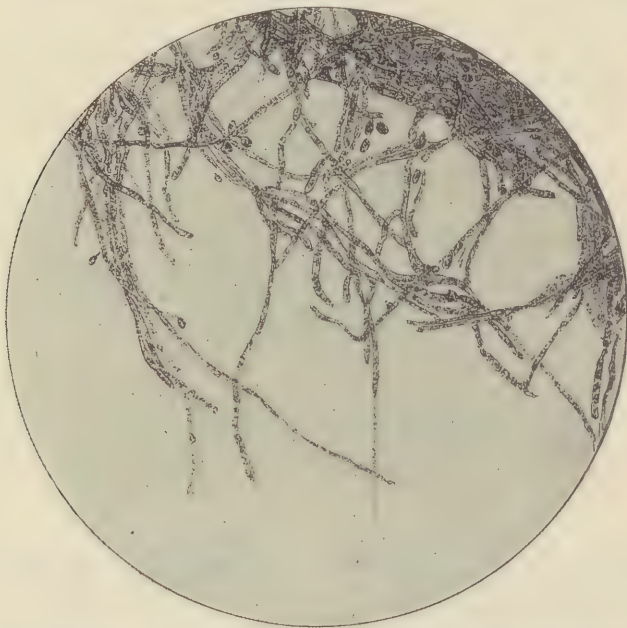


FIG. 156.—*Sporotrichium*. Four-day-old colony in plain bouillon; methylene blue oil immersion, showing septa in mycelium. (Hamburger.)

In addition to this fungus (*sporotrichium*) found growing in the abscesses there are a number of other moulds and yeast-like plants that act in a similar manner. For these latter the term mycosis may be given (variously named blastomycosis, oidiomycosis, saccharomycosis), and the plant can be cultivated and studied and its morphology and life history fully determined in most instances. As soon as the plant can be removed or killed the ulcers heal.

¹ Sporotrichosis in Man, by Dr. W. W. B. Hamburger, Jour. Am. Med. Assn., 1912, lix.

Crown Gall.—Crown gall is a disease which occurs on a variety of plants and any part of the root or shoot is liable to attack. It consists of an irregular growth which frequently becomes larger than the root or shoot upon which it occurs. In this growing mass of cells the conducting tissues are imperfectly developed. The way that the cells grow and their manner of dividing tend to place this disease quite apart from the usual diseases in plants, locating it in the category of the true tumors; it is believed by Smith that the conditions are similar to animal tumors.¹

The cause of this disease has been an unsolved problem until the recent work of Smith and others. The successive steps employed in demonstrating that crown gall is due to a definite organism were the following: *First*, galls were crushed in beef broth, from which agar plate cultures were made, which were kept at temperatures varying from 20° to 30° C. The galls were thoroughly cleaned and modern antiseptic methods used. The *second* step was the finding of a definite organism to which the name *Bacterium tumefaciens* was given, growing on the agar-culture plates (Fig. 158).

The *third* step was to demonstrate that the bacteria isolated on the agar plates would cause a similar growth when introduced into the tissues of a healthy plant. On June 1 inoculations were made into the stem of young healthy daisy plants growing in the pathological greenhouse. On June 18 a distinct elevation was visible at each point where an inoculation had been made.

The *fourth* step was the study of these new galls and the finding of the same organisms present. The infectious nature of these organisms was proved by inoculating healthy plants which in turn produced galls. This method of conclusively proving that a given disease was caused by a given organism was formulated by Koch.



FIG. 157.—A natural infection of crown gall in the hothouse which has probably resulted in the transfer of the germs by way of the gardener's hose in watering. (E.F. Smith.)

¹ Smith, Brown and Townsend: Crown Gall of Plants: Its Causes and Remedy, Bureau Plant Industry, Bull. No. 213. Smith, Brown and McCulloch: The Structure and Development of Crown Gall: A Plant Cancer, Bureau Plant Industry, Bull. No. 255. Smith, E. F.: Further Evidence that Crown Gall of Plants is Cancer, Science, June 23, 1916, p. 871.

The bacteria causing this disease are located inside the cells, and it is the "stimulus of their presence which causes the cell to divide abnormally by throwing it out of balance." After the crown-gall tumor has been grown another series of changes begins. It seems

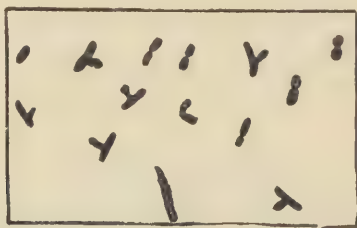


FIG. 158.—*Bacterium tumefaciens*. (E. F. Smith.)

that the soft tissues cannot be adequately nourished beyond a certain limit, and decay sets in. "A variety of saprophytic bacteria and fungi take part in disintegrating the overgrown tissues. Among



FIG. 159.—Plant inoculated November 26, 1907, and photographed March 8, 1908. (F. F. Smith.)

these saprophytic bacteria there are several white forms closely resembling the gall organism as grown on agar-poured plates, dendritic white forms, green fluorescent species, yellow species, orange species, pink species, etc."

PLATE II

FIG. 1

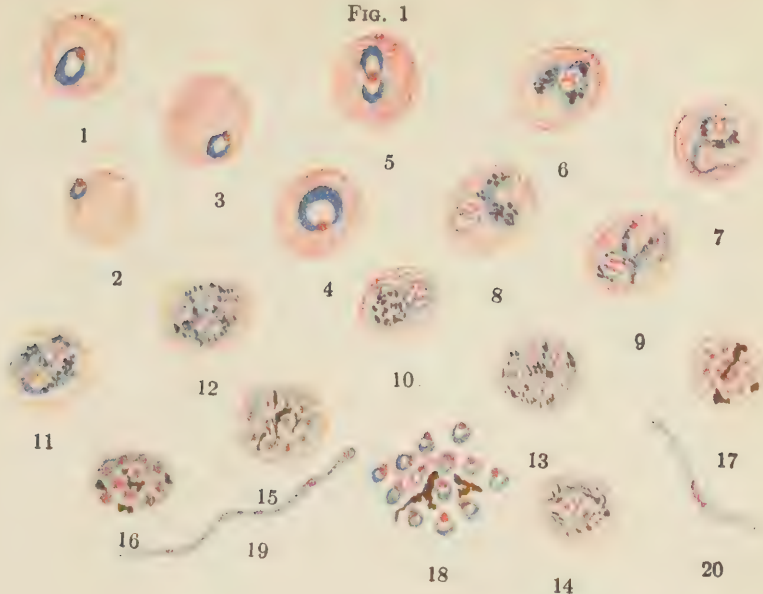
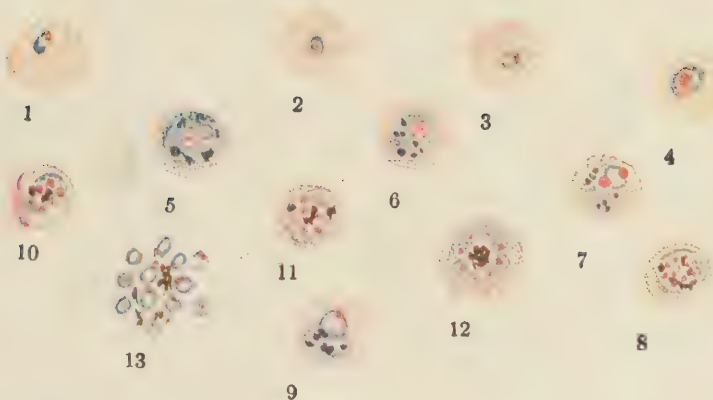


FIG. 2



CHARLES E. CRAIG, DEL.

Fig. 1.—Tertian Malarial Plasmodium. Stained by Oliver's Modification of Wright's Stain.

- | | | |
|--|--|--|
| 1 to 4. Ring forms of tertian parasite. | 11 to 14. Nearly full-grown forms, showing diffusion of the chromatin. | 18. Segmenting forms after destruction of red corpuscle. |
| 5. Ring form. (Conjugation form of Ewing.) | 15 to 17. Segmenting forms within red corpuscle. | 19. Microgamete. |
| 6 to 10. Pigmented organisms. | | 20. Sporozoite. |

Fig. 2.—Quartan Malarial Plasmodium. Stained by Oliver's Modification of Wright's Stain.

- | | | |
|---|---|--|
| 1 to 4. Ring forms of quartan parasite. | 10 to 12. Segmenting forms of quartan parasite. | 13. Segmenting stage after destruction of red corpuscle. |
| 5, 6, 7, 8, 9. Pigmented parasites. | | |

NOTE.—Chromatin of nucleus stained red ; protoplasm stained blue ; vesicular portion of nucleus unstained.

This disease serves to illustrate the method of determining the exact cause of a biological disease. The growth of the cells in crown gall is believed to be due to some stimulus produced by the bacteria as they live naturally, although as parasites within the cells. When the original disease reaches its limit a number of disintegrating bacteria begin to live upon this abnormal growth, with the result that decay sets in and parts slough off, causing an open wound. The organisms which bring about all of these undesirable results are definite living things which have a specific structure and life history.

Malaria.—When this disease was first recognized it was thought to be associated with bad air and was therefore named malaria. In 1881 a French military doctor located in Algiers, Dr. Laveran, discovered in the blood of some malarial patients a new organism which he declared to be the cause of the disease. It was more than fifteen years after this discovery before definite information was available as to the source of this parasite in the human blood. The name *Plasmodium malaria* was given to this organism because of its

supposed resemblance to some of the plasmodia-forming fungi. Authorities differ as to the exact number of malarial parasites, but they all belong to the animal kingdom and are protozoa, class sporozoa, order hemosporidia (see page 97).

The malarial parasite is not able to complete its life history in the one animal (the frog, reptile, bird or mammal) in which it first occurs, although it may live continuously for many months in the human body. The malarial plasmodium passes through a series of changes in the human blood as follows: The parasite penetrates a red blood corpuscle, where it increases in size until it nearly fills the blood cell (Plate II, Fig. 15). The time that it remains in the cell depends upon the kind of parasite, whether it be a one-day, a three-

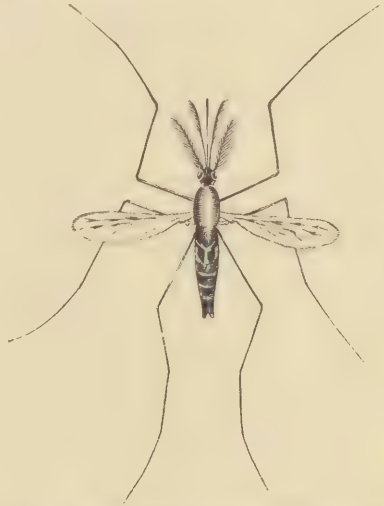


FIG. 160.—*Anopheles maculipennis*. Male.
(Harrington.)

day or a four-day form. At first the parasites are not very numerous, but after a few weeks their number is very great. As they all belong to the same original brood they reach maturity in the blood cells at the same time, and all are liberated from the blood cells at regular intervals. The fever accompanying this disease coincides with the liberation of a new swarm of parasites. The waste products of the parasite metabolism are also set free at the same time and assist in setting up disturbances in the body. After a time the parasites develop into two forms, which are the sexual phases, the *macrogametocytes* and the *microgametocytes*. These cells do not fuse while the parasite remains in the human blood but in the stomach of the anopheles mosquito. The fertilized cell makes its way into the lining epithelium of the intestine of the mosquito and comes to rest in the submucosa. Here it undergoes a series of divisions and ultimately gives rise to a stage known as a *sporozoite*. Some of these *sporozoites* make their way into the salivary glands and thence into the proboscis of the insect, from which they escape into the blood of man. The non-sexual forms of the parasite which are drawn into the stomach of the anopheles mosquito are destroyed. Should a culex mosquito suck up the blood of a malarial patient all of the parasites are digested. And when an anopheles mosquito sucks the blood of a bird in which the organism *Plasmodium præcox* (causing estivo-autumnal fever) occurs the parasites are all digested.

Malaria is a disease that is distributed all over the United States and especially in the South. It can occur only through the patients being bitten by an anopheles mosquito which has the *Plasmodium malaria* in its salivary glands. It is a serious disease in some sections, and in 1900, 14,909 persons distributed throughout the United States died from it. There is no way of estimating the number who were incapacitated from working because of this disease. The writings of many of the Roman authors contain references to destructive epidemics of malaria, and the efforts to drain the deadly Campagna date back for many years. The first capital of Alabama, St. Stephens, which in 1810 was a thriving town, was literally wiped out of existence because of the prevalence of malaria. The present sanitary knowledge of malaria makes it entirely safe to live anywhere in the world if one simply protects himself from the bites of the anopheles mosquito by keeping behind a screen (nineteen meshes to the inch) after dark.

The Bacterial Diseases.—The several diseases (typhoid fever, tuberculosis, diphtheria, colds, pneumonia, gonorrhea, leprosy, tetanus,

etc.), caused by some specific bacterium may be discussed under one heading in explaining their biological relations. Each disease has its own marked symptoms and recognizable germ, but so far as their biology is concerned all are similar. The bacteria gain access to our bodies and live parasitically, during which time the disease develops. The bacteria grow and multiply and carry on their own metabolism. *The result of this normal activity on their part is the production of poisons which disturb the cells of the human body; just what cells are interfered with depends upon the invading organism.* Each disease passes through several stages or cycles. The first of these stages is termed the incubation period and is the time that elapses between the entrance of the infection into the body and the day when the earliest symptoms appear. This idea of a period of incubation is well illustrated in the following table:

DISEASE WITH SHORT INCUBATION.

	Limits.	Usual time.
Diphtheria	2 to 7 days	2 days
Scarlet fever	1 to 8 days	3 to 4 days
Influenza	1 to 4 days	2 days
Erysipelas	3 to 7 days	4 to 5 days

DISEASE WITH LONG INCUBATION.

	Limits.	Usual periods.
Typhus fever	7 to 14 days	12 days
Typhoid fever	7 to 21 days	about 14 days
Chicken-pox	10 to 15 days	about 14 days
Smallpox	9 to 15 days	generally 11 or 12 days
Measles	7 to 18 days	generally 14 days
German measles	12 to 21 days	about 14 days
Mumps	14 to 21 days	about 16 days
Whooping-cough	7 to 14 days	about 10 days

The next stage is sometimes called the termination period, and there are various ways in which the disease comes to a close. The steady course may end abruptly, as in typhoid fever, and convalescence set in at once, or the decline may be very gradual, and it is difficult to say just when it stops. The last stage comprises the changes occurring in the return to ordinary health and is termed convalescence. Each bacterial organism living in this parasitic relation shows certain peculiarities, as does the host, so that the conditions in any two cases are never exactly the same. The changes which the bacteria cause in the cells and tissues are likewise varied, so that general statements must be made; in one case ulcers appear, in another abscesses are formed or certain glands are swollen, etc.

In the study of the bacterial diseases great care has been exercised to definitely isolate the specific germ that is the cause of the disease and work out its life-history and habits, as a result one can learn how to avoid infection by such germs. The number of persons dying annually from the bacterial diseases is very large, as one soon realizes from a study of the reports from any State board of health, but

he also gains from such study the further important fact that all of these diseases are preventable. Whether the sanitary conditions of civilized nations will ever become so perfect as to prevent any considerable number of the bacterial diseases is a question, but it is the purpose of those who understand the wastefulness that comes from sickness and death due to these diseases to try greatly to reduce their number. The greatest work for medicine in the future is to be the prevention of disease instead of its cure.

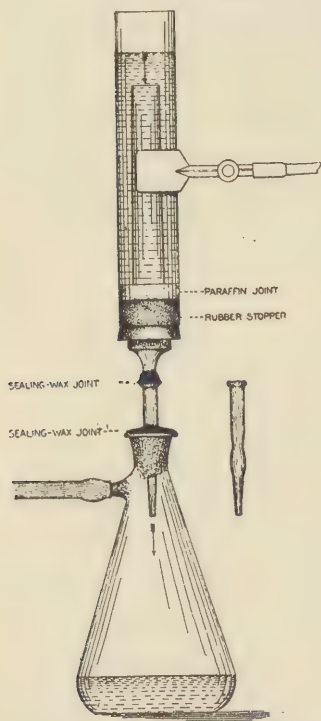


FIG. 161.—Chamberland filter. The central structure is an unglazed porcelain cylinder, through which the fluid is drawn by suction and filtered.

The Filterable Viruses.—At present there are some thirty diseases of human, plant and animal life which have been demonstrated to be due to organisms that can pass through a Berkefeld or Chamberland filter, and all of these are at present invisible with the highest powers of the microscope. Of the diseases which affect man the following may be mentioned: Foot-and-mouth disease, rabies, vaccinia, smallpox, yellow fever, dengue fever, trachoma,

poliomyelitis, typhus fever, measles and scarlet fever. In most of these diseases the unknown germ is transmitted by some intermediate host, such as mosquito or body-louse. In the next few years much that is new will be added to our knowledge of this group of diseases.

Tape-worms, Hook-worms and Others.—There are a number of highly developed animals that live as parasites mostly within the digestive

canal in man and other animals. These are the well-known thread-worms, tape-worms, hook-worms and others. Their chief harm consists in either absorbing the nourishment taken by the host before it leaves the digestive canal or in the absorption of blood. The food being ready at hand in sufficient quantity, they have but to grow and reproduce until in some cases they become very numerous. It is not practical to make many general statements concerning this group of diseases because each animal has its own life-history and mode of entering the body. Some, like the tape-worm, have a complicated life-history, as already shown on page 158; while others, like the hook-worm, readily pass from man to man without an intermediate host. Hook-worm is an ancient and world-wide disease that belts the earth in a zone about 36° north to 30° south parallel. In some parts of this district, like Samoa, 70 per cent. of the population, in southern China 75 per cent., in India from 60 to 80 per cent., in Dutch Guiana 90 per cent., are found to harbor hook-worms. The economic loss from a disease so widespread is enormous. A physically sound coffee-picker in Porto Rico picks 500 to 600 measures a day; the hook-worm infected picker averages from 100 to 250 measures. The effects of this disease in stemming the progress of civilization in China, India, Egypt and other countries cannot be measured. The practical aspect of the question comes in determining the admission of immigrants from hookworm countries. In 1911 a shipload of Indian coolies landed at San Francisco and when examined 90 per cent. were found to be infected. A low class of immigrants with their lack of sanitary knowledge becomes a center from which such diseases spread. Dr. C. W. Stiles, the great authority on this disease, believes that the sanitary privy in the non-sewered districts of the Gulf-Atlantic States and the wearing of shoes are the most important measures in preventing the hook-worm disease.

Animal Tumors.—Just how the various abnormal growths so frequently found in all of the higher animals are to be explained remains to be discovered. The recent studies on crown gall suggest that the cause may be due to microorganisms which our present technic does not reveal. This suggestion has much force in it when it is remembered that there are several diseases due to the so-called filterable viruses. These tumor-like growths are found in all of the vertebrates. A characteristic instance is shown in the kidney of the frog. This organ is usually regular in outline and of a dark red color. It is about 14 mm. long and 4 mm. wide. The kidneys shown in Fig. 163 were 21 mm. long and 8 mm. wide, and irregular

in outline. The color of the fresh diseased kidney was whitish. Each kidney has a large number of lobes. The tumor growth is so extensive that the original kidney is revealed only in blotches and the ureter is carried around to the inner edge instead of being



FIG. 162.—A normal-sized kidney in the frog ($\times 2x$), showing the normal adrenal.



FIG. 163.—The dorsal and ventral view of the right kidney of the frog having the adrenal tumor.¹ $\times 2x$.

on the outer edge of the kidney. The cells were in active stages of division and showed the usual atypical forms (Fig. 163). The conditions in the frog are similar to those that are often found in human adrenal tumors. It is greatly to be hoped that these strange abnormal growths in man and other vertebrates will finally be shown



FIG. 164.—Nuclei showing atypical mitosis characteristic of the adrenal tumor in the kidney of the frog.

to be due to microorganisms, for then science can probably tell us how to prevent them.

Disease Carriers.—The part played by biology in helping to solve the nature of disease and of the various organisms that infect the

¹ Adrenal Tumors in Kidney of the Frog, *Anat., Anz.*, 1905, Bd. xxvi, No. 24.

body has been great, but biologists found an equally fertile field for study in unravelling the manner in which disease was carried from the sick to the well. The recognition that definite living organisms are responsible for the transmission of disease has revolutionized the methods employed in fighting the further spread of many of the infectious diseases. *The term carrier is given to animals or persons who, apparently in good health, harbor and spread disease germs.* The fact that a man appears well and yet may be spreading disease is a new idea in preventive medicine. This in no way eliminates the old idea that contact with the sick furnishes a means of transmission of disease but rather adds another source of infection. Dur-

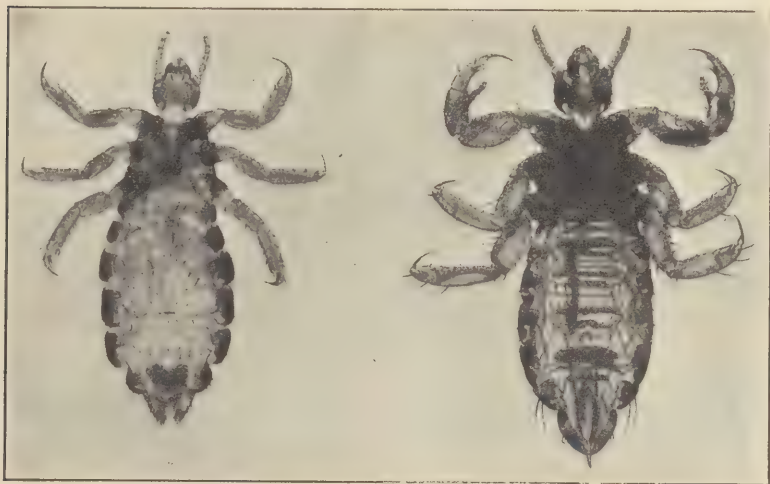


FIG. 165.—Male and female cooties, carriers of trench fever. Photograph furnished by U. S. Bureau of Entomology.

ing the convalescence of a patient it is to be expected that some germs will be found, but their persistence in a person after he is well or their existence in a person who has never had the disease is difficult to explain. Among men there are (1) convalescent, (2) chronic and (3) healthy carriers. Diphtheria and typhoid fever are two common diseases in connection with which carriers are found. The spread of epidemics is now frequently traced to a person who believed himself to be perfectly free from such germs. The elimination of the sporadic cases of diphtheria in certain schools is now readily accomplished by simply locating the diphtheria carriers in the school. Malta fever furnishes an interesting illustration of the principles

involved. This disease is due to *Micrococcus melitensis*. The goat is really a chronic carrier of these bacteria. When the goats on the island of Malta were examined by the British Commission fully 50 per cent. gave a test which showed that they were harboring the germs and 10 per cent. were actually secreting the bacteria in their milk. All that was necessary was to boil the goats' milk or avoid using it to put a stop to Malta fever. In a similar way milk tuberculosis is caused.

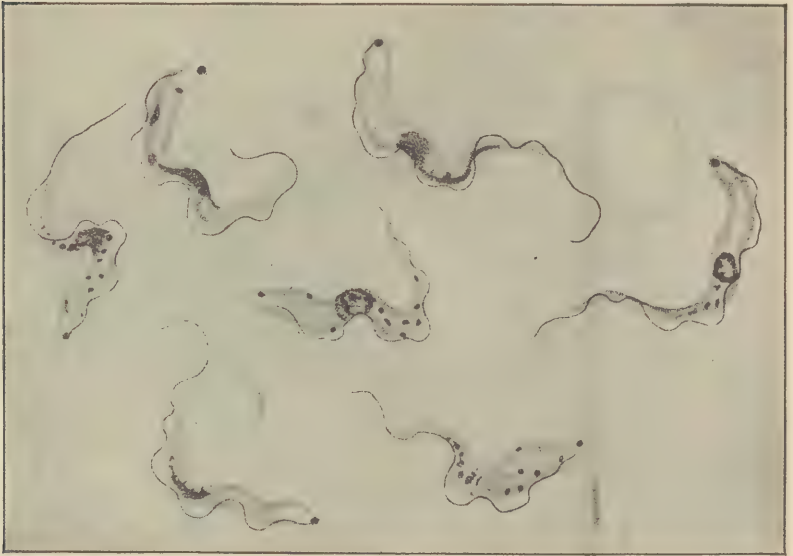


FIG. 166.—Trypanosomes (*T. gambiense*) from the blood in sleeping sickness. $\times 2000$. (Bruce.)

The part played by animals in acting as carriers for the protozoan diseases is of great importance, for they may act as the natural reservoirs of the virus and are thus responsible for the continued existence of the disease. Among the animals that act as carriers of the protozoa the insects rank first. Their relation to the animal germs is a passive one when they accidentally convey them and active when they are really diseased. The fly¹ feeding upon the excreta of typhoid patients may carry the typhoid germs on its body and when it alights upon food simply leave them; or the

¹ The House-fly, *Musca Domestica* Linn: Its Structure, Habits, Development, Relation to Disease and Control. By C. Gordon Hewitt, Cambridge University Press.

anopheles mosquito may be diseased by the malarial plasmodium and under proper conditions, on biting a person, transmit the malarial germs. The bubonic plague furnishes one of the best illustrations of the part played by insects in acting as carriers. This disease is spread by the bite of fleas which come from rats or squirrels that have been infected. The plague bacillus develops in the digestive canal of the flea and escapes with the excreta. While the flea seems to be unaffected by the presence of these germs, if the excretal matter of such fleas comes in contact with a wound, according to Hindle, the infection occurs, although it may be contracted through the salivary secretion.

The Prevention of Disease.—This is the field in which humanity can do its greatest work. The task is stupendous. The mere facts that certain diseases, like hook-worm, extend in a belt around the world and among the lowest forms of civilization, that tuberculosis is killing thousands annually, that malaria and yellow fever have devastated cities, and bubonic plague unrestricted may sweep through a nation, reveal something of the scope of the problem of prevention. *All diseases which are due to the presence of some organism are preventable, and this fact alone is one to furnish all with enthusiasm for a work that must continue for many years to come.* An important incident in the United States which indicates that there is a responsibility in the matter of preventing disease is the recent decision of one of the courts in Minnesota that a city is responsible for the purity of its water supply, and that when a person contracts typhoid fever and dies his heirs can sue the city for damages. Such a decision is an indication of progress. The world-wide dissemination of the truth about disease is an undertaking which will require years, but which must be accomplished in order to prevent the spread of plague from nation to nation.

Scientists are able to approach the problem of prevention in an intelligent manner because of the recent discoveries in regard to carriers.

The first step in the progress of prevention is to destroy the insect carriers when practicable or to destroy or prevent their eating in order that they may not be able to reproduce.

Human beings who act as carriers must be isolated until free from the germs or be prevented from working at trades such as dairying and cooking, which enable them to spread the germs. It is sometimes necessary to quarantine chronic carriers. The insect carriers, with proper care, can be prevented from biting human beings, as is

illustrated by the conditions in the Panama Canal Zone, which used to be like Havana a pest-hole of disease. After a time the insect carriers should become free from disease germs if the germs are not allowed to gain access to them. When civilization has developed to the stage that all realize that disease from parasitism is wholly preventable, and that every epidemic is the result of carelessness, then we may expect that sanitary precautions will be observed. After the greater part of the United States has been free from any epidemic of smallpox for some years, people grow careless and neglect to be vaccinated, and it breaks out again. Eternal vigilance is going to be the price that all must pay for protection from the preventable diseases even after their prevalence has been greatly reduced from what it is now, even after the world recognizes that the problem is a work in which every nation must do its part.

Immunity.—Disease has been known from remote times and yet numerous plants, animals and men inhabit the globe. These have survived the ravages of disease or have never succumbed to infection. It is well known that there is a natural resistance to disease which men possess unequally; some are never sick and others seem to be unable to resist any form of disease. Again, our powers of resistance are higher under certain conditions than under others. This power to resist the organisms that invade our bodies is immunity, and natural immunity is the degree of immunity that each person possesses. Immunity has two aspects—resistance to the microorganisms themselves and resistance to the microbial poisons.

When microbes gain access to the body of a paramecium, for example, the paramecium treats them as it would any ingested particle of food, and if the protecting cell walls of the germs cannot be broken down the germs are eliminated. If the microbial toxins are brought in contact with these and other ciliate protozoans there is no appreciable effect upon the protozoa. They are able to tolerate the poisons. It has been known for some time that these simple animals are able to adapt themselves not only to altered physical conditions but to endure the toxic action of true poisons. In studying the fundamental properties of living matter this adaptability of living protoplasm must be ranked as one of the most important.

The problem of immunity is further illustrated by the degree of tolerance which different animals have to the same poisons. It is well known that sheep are the most susceptible of the mammals to the toxin of tubercle bacilli, while the guinea-pig is not very

susceptible; but the guinea-pig is very susceptible to the tubercle bacilli and the sheep is very resistant, *therefore immunity to the poisons and immunity to the germs represent two distinct conditions.* The snail (*Helix pomatia*) resists the introduction of large quantities of anthrax bacilli and they soon disappear from the blood and are found in the cells of the foot, especially those which surround the pulmonary vessels. During this taking up of the anthrax bacilli the snail remains in good health. Forty-eight hours after the injection of the bacilli these cells afforded cultures which were capable of giving fatal anthrax to mice. Ten days or more passed before the phagocytes which had engulfed the bacilli had fully digested them. If anthrax bacilli are injected into the body of the perch, numerous leukocytes accumulate around and ingest them, although the peritoneal fluid furnishes a suitable culture medium for these bacteria. These and other illustrations that might be added serve to show that many animals have a natural immunity not only to the microbial poisons but also to the microbes themselves.¹

Given this natural immunity, which is found to be generally distributed among all forms of life, how does it happen that there is any sickness? It is not easy to answer this question in a word or in an elementary course, but it may be suggested that *a sufficient number of germs within the body is necessary and that these germs must be virulent and the host receptive.* We are unable to state just what the conditions are that make a host receptive to germs or how to eliminate the condition. We say that the non-resistant host is susceptible, the resistant immune. When the germs have gained entrance to a susceptible host, does the disease begin as a result of their parasitic habit or are there other factors? The parasitic nature of disease was the early conception, but it was soon found that there were a number of conditions that mere parasitism did not explain. The disease frequently followed a course that suggested that it was similar to the fermentative action of yeast, etc., and so there arose the zymotic theory of germ disease. Later it was found that the natural living processes of the bacteria produced certain waste substances, by-products of growth which were of a poisonous character, and that some of the phases of a given disease could be induced by injecting the poison. There was thus added the toxic factor of disease. This is a most important phase of the cause of the bacterial diseases, as some of the disease bacteria show

¹ For the detailed study of immunity, the student is referred to Metchnikoff: *Immunity in Infectious Diseases.* Ehrlich: *Studies on Immunity.*

very little growth in the human body. Many writers hold that these two processes should be united and that the cause of the disease is "zymotoxic." The details of this theory as well as the details connected with recovery from disease are taken up in advanced courses. It must suffice here to mention in brief outline some of the main points.

The disease germs are destroyed by the phagocytes which ingest them and this process is fundamentally a feeding process just as is

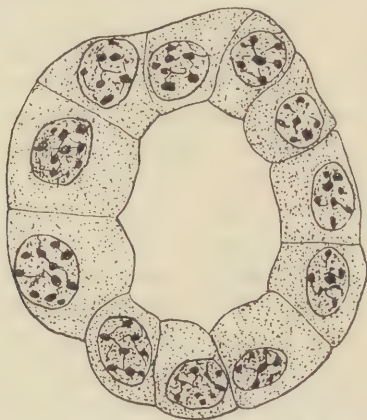


FIG. 167.—Kidney cells of normal frog. Compare these cells with those in Fig. 167.

the case in the protozoa, but they are also destroyed by the juices of the body. It is believed that the body is able to secrete certain substances (antitoxins) which have the property of neutralizing the toxic products of the bacteria and this gives the cells of the body a chance to recover. As a result of having had certain diseases one is said usually to be protected from a second attack. This is the case with most of the childhood diseases, such as measles, whooping-cough, etc. When the cells of the body have become thus protected against a second attack the term *acquired immunity* is used to distinguish it from the natural immunity which was not sufficient in such cases to prevent the disease. Acquired immunity is not a permanent condition of the cells and may disappear after one, two, three or more years.

Protection and Adaptation.—Since Jenner, in 1798, attempted to imitate nature and produce an immunity to certain diseases, men have been anxious to find a means of protecting their bodies from

the ravages of disease. There are now some dozen or more diseases which have their antitoxin, vaccine, etc. If it were possible to remove the germs which cause disease all of these would be unnecessary. The underlying principle in the use of these protective agents (and there must be a specific one for each disease because the toxin produced by each different germ is distinct) is gradually to accustom the cells of the body to the poison in a mild form, so that during the process they will elaborate antibodies to the particular poison

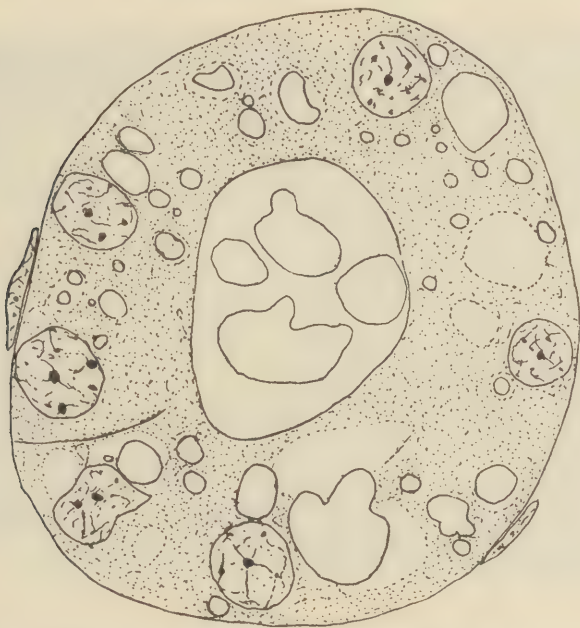


FIG. 168.—Cross-section of kidney tubule of hemorrhagic frog. The bodies with a continuous outline in the lumen and in the cytoplasm are the degenerating red blood corpuscles. This is an illustration of adaptation in the cells of the kidney to meet an emergency—the hemorrhage. (Kidney Cells of the Frog in a Phagocytic Role, *Anat. Anz.*, 1908, Bd. xxxii, No. 8.) How do the nuclei in these cells differ from those in Fig. 167?

produced by the given organism. It is significant to note in this connection that an antibody appears in the blood whenever protein is artificially introduced into the blood. When proteins are thus injected into the blood they act as a poison, which furnishes an artificial condition that closely approximates the toxin condition arising from bacteria. There has recently been discovered a new species of antelope in East Africa, the rock-loving, klippspringer.

This species is bush-feeding and regularly eats the leaves of a bush that belongs to the genus *Strychnos*. This is the plant from which the deadly drug strychnin is obtained, which, indeed, is a strange adaptation. The principle thus employed is as old as the study of biology and is everywhere apparent in nature. This adaptation is one in which the living protoplasm of certain cells plays the important part. Tuberculosis may occur in the lungs; diphtheria has its location in the throat or nose; while typhoid fever is found in the blood and may be localized in the intestines, and it may be assumed



FIG. 169.—Photograph of a spruce tree which has tipped over, due to the action of the waves on the roots. The tip of the tree has adapted itself to this new position, while two of the branches have become tree-like in their symmetry and bear cones. This adaptation is especially interesting, because it shows how the tree underwent a radical modification in attempting to adjust itself to its new position. The tree-like symmetry of the two limbs is a conspicuous illustration of this change.

that the cells which acquire an immunity to each of these diseases are not the same. In vaccination against smallpox the germs of cowpox, a mild form of smallpox, are introduced into the body, and through the reactions of the cells of the body to the cowpox virus the subject acquires a greater power to withstand the virulent smallpox virus. This acquired toleration lasts through a variable number of years, but usually not more than seven. Intelligent people always keep themselves immune to smallpox, because no one can tell when or how he will be exposed. All modern nations are

immunizing their soldiers against typhoid fever, and the result has been almost entirely to prevent typhoid fever among our soldiers during 1917-1919. Men and women in civil life should become immunized against typhoid fever unless they can be confident that their water and milk are kept pure. The shop, the factory, the dairy, the mine, the canning industry, the meat-packing concerns, etc., all have or must adopt a new regimen as a result of the discoveries in biology during the past twenty years. State and national legislation is being enacted to compel such industries to recognize the



FIG. 170.—Photograph of cup coral taken at Bermuda. A heavy wind storm nearly buried in the mud the coral at the bottom and left of the figure, leaving one corner uncovered. The animal free from the mud grew up at the angle shown in the figure. The coral in adapting itself to the extremes of its environment grew in this asymmetrical manner. This figure, like Fig. 169, gives one some idea of the extent and possibilities of adaptation in nature.

fundamental rights of human beings to have a clean place to work, a clean place to live and clean food to eat.

CHAPTER XXI.

OTHER ADAPTATIONS.

THE somewhat detailed presentation of adaptations in the two preceding chapters serves to show the method of analysis and the significance of this phase of biology. The adaptations in this chapter merit just as extensive treatment but the limits of an elementary text-book do not permit it. The purpose of this chapter, then, is to outline briefly some of these additional biological adaptations with the expectation that you will consult the references at the end of the chapter for fuller details.

Oxygen.—Every living thing requires oxygen and we have studied several structures that assisted animals in securing the necessary amount. The skin and lungs of the frog are both respiratory organs, the lungs being used mostly in the summer while the skin must suffice during hibernation. During the tadpole stage gills are utilized (Fig. 62). In your first laboratory study, you found that these three distinct organs were employed in securing oxygen. The earthworm, on the other hand, uses its skin entirely as a respiratory organ, although there are some other annelid worms that have clearly defined gills. Crayfish cannot take in oxygen through the skin on account of the formation of lime salts which unite with the chitin to form an exoskeleton, but definite gills are found beneath the edge of the carapace that enable the crayfish to carry on the respiratory process (Fig. 125). Fishes also have gills, but they are not to be regarded as identical in origin with the gills of crustaceans (Fig. 9). Here, then, is a similar adaptation arising in widely separated types of animals. What organs do whales and seals use in getting oxygen? Insects, which are closely related to crustaceans, breathe by means of tracheæ that ramify throughout the entire body, even penetrating into the nerve ganglia.

Food-getting.—Formulate your own outline of the manifold adaptations which animals have to assist them in securing their necessary food energy.

Sense Organs.—Possibly no better illustration of adaptation can be cited than the sense organs of animals, each of which is specialized

to respond to conditions in the environment. The compound eyes of the crayfish and the eyes of the frog are stimulated by ether waves vibrating between 400,000¹ billion and 800,000 billion times per second. Such vibrations produce light and color and the only sense organ that can be stimulated by these waves is the eye. When the ether vibrates more than 800,000 billion times per second as it does, animals and man have no sense organs that enable them to become aware of the ultraviolet rays, x -rays or the emanations of radium, which we have come to know about through the use of special physical apparatus.

A study of the physical vibrations in nature reveals that we have sense organs for only a small number of them. We all know that the human ear responds to vibrations from 30 per second to 30,000 and that we have no sense organs that are responsive to vibrations below 30 per second and none above 30,000 until we come to 3000 billion vibrations when the skin gives us the sensation of heat. In the



FIG. 171.—Salamander, showing the location of the lateral line sense organs. Each spot represents a pore opening into a canal in which are special sense cells (Fig. 35, B). The exact distribution of these sense organs varies with each species. This species is *Gyrinophylis porphyriticus*, one-half natural size.

aquatic vertebrates are found some special sense organs that are believed to respond to vibrations below 30 per second. These are the lateral line organs (Fig. 171).

A little reflection on your part will easily convince you that we live in a world in which our sense organs give us incomplete information concerning the activities in the physical universe; in short, we possess sense organs adapted to give us information on scarcely more than half of the physical vibrations constantly about us. The sense organs thus serve to reveal the extent to which protoplasm has become modified under adaptation and the limits of protoplasmic adaptability in that animals have never developed sense organs to respond to many of the physical vibrations.

Reproduction.—In classifying reproduction under adaptation it is not intended to suggest that this fundamental characteristic of living

¹ See Herrick: Introduction to Neurology. Table of Physical Vibrations.

protoplasm is an adaptation but rather to direct attention to the significant results that follow from normal reproductive activity. Attention has already been directed to Professor Woodworth's experiments on paramecium (page 93). The rate of reproduction observed in these studies was three divisions in forty-eight hours, and at the end of the experiment, the animals appeared as healthy as in the beginning. During this time, if all generations could have been observed and all had been as 'active' as the strain preserved, there would have been a mass of paramecium protoplasm more than 10,000 times the mass of the earth!



FIG. 172.—Blue crab, *Callinectes sapidus*. The young hatch from eggs borne for about fifteen days upon the swimmerets of the abdomen of the female in a mass called a sponge. There are about 1,757,000 eggs in one sponge. A female crab may lay two and probably more batches of eggs during the course of her life, the spermatozoa from one copulation sufficing to fertilize successive lots of eggs. (Photograph and legend from Churchill.)

"An oyster may have 60,000,000 eggs, and the average American yield is 16,000,000. If all the progeny of one oyster survived and multiplied and so on until there were great-great-grandchildren these would number 66,000,000,000,000,000,000,000,000,000,000, and the heap of shells would be eight times the size of the earth!" Lull.

The insects show a similar form of reproductivity. A single flesh-eating fly (*Musca carnaria*) produces 20,000 larvæ, and these grow so quickly that they reach their full size in five days. Each of these larvæ remains in the pupa stage about five or six days, so that each parent fly may be increased two thousandfold in a fortnight. The

great Swedish naturalist Linnaeus asserted that a dead horse could be devoured by three flies as quickly as by a lion.

Even some of the vertebrates show reproductive possibilities that would soon pack the ocean full of fish as the following taken from Lull shows: Among the lower vertebrates where no paternal care is given to the young the potential productivity is necessarily enormous. In four herring the number of eggs varied from 20,000 to 47,000; in a cod there were 6,000,000; a turbot, 9,000,000; and a ling, 28,000,000, and yet despite the enormous number of offspring which might possibly be produced from a single pair in one generation, the ultimate number of herring or cod or ling remains on the average about the same. The chance of survival, therefore, of a ling's egg is one in fourteen million.

Even the slow breeding of our common robin which raises annually one or two broods with an average of four young in a brood would produce in a short time so many robins that they would have to starve because there would not be enough robin food for them in the entire world. The following table from Metcalf shows how many robins there would be at the end of ten years:

	Adult.	Young.
One pair of adult robins	2	4
Second year	6	12
Third year	18	35
Fourth year	54	108
Fifth year	162	324
Sixth year	486	972
Seventh year	1,478	2,916
Eighth year	4,374	8,748
Ninth year	13,122	26,244
Tenth year	39,366	78,732
End of tenth year	118,095	

When one considers the energy required to produce such vast numbers of eggs and sperms some insight into the real meaning of this fundamental characteristic of protoplasm is gained. The production of so many living things causes keen competition for a place to live, for food and for an opportunity in turn to produce young, the significance of which is presented in the next general section of the text.

Regeneration and Grafting.—In the study of hydra attention was directed to the fact that these animals could regrow lost parts and that they could be grafted (Figs. 109, 110). At first scientists were inclined to regard this property as a phase of reproduction but it differs from reproduction in that it does not take place as a method of producing more individuals but in the repair of injuries. Grafting is not known to occur in nature.

Among all of the lower animals and plants a large amount of regeneration may take place, even to the regrowing of the legs on the crayfish or the tail and legs of an Amphibian. But as we pass to the higher animals this general property of regrowing lost parts is restricted to specific organs (Fig. 173), such as scales, feathers, hair, the outer skin or the healing of a broken bone. With the higher specialization of structures there has come a loss of the property of regeneration.

Biologists regard the study of regeneration and the experiments in grafting as very important in revealing a particular phase of protoplasmic adaptation that was overlooked for a long time. The special studies in this field of biology suggested and laid the foundation for certain phases of modern surgery in man.



FIG. 173.—American elk. The antlers are borne only by the male and are shed annually in March. These interesting structural adaptations are to be regarded as secondary sexual characters.

Habit Adaptations.—The early studies in adaptation dealt especially with the modifications in the various parts of animals. These are more obvious than a physiological property. We shall simply enumerate them because their presentation would require many pages, but especially because you should become familiar with the general literature on this subject. Lull devotes one hundred pages to a discussion of these adaptations and makes the following classification: Cursorial or speed adaptations dealing with the modifications in form which help vertebrates to escape their enemies on land, in water or in the air; fossorial or adaptations to a subterranean life, such as those

who dig or burrow for food; aquatic adaptations dealing with the general form of the body and the organs of locomotion in such form as fishes and whales; scansorial adaptations where animals become partly or wholly arboreal; volant or flying adaptations in fishes, reptiles, birds and mammals; adaptations to cave and deep-sea life.

Color.—The subject of color while clearly an adaptation is more often treated under the theoretical aspects of biology, but there are certain facts of color which should precede an attempt to explain the meaning of color in nature. No training in biology is necessary to indicate to one the range of color in nature. Even in the north temperate region there is much variety, but this is insignificant in comparison with what is found in the tropics.

Organic color is produced in just the same way that color in the inorganic world is formed. There is some interference with the rays of light either by pigment or by the structure of the surface on which the light falls. The former are known as the chemical or pigment colors and the latter as physical colors. It frequently happens that a given color is due to a combination of these two causes, which is then known as a chemico-physical color.

Chemical colors are found in all parts of the animal body, such as the hemoglobin of the blood, a red color due to an iron compound or a brown pigment in the kidney. The skin of the frog has brown blotches, due to pigment in the dermis, while fat pigments, called lipochromes, are abundant in the feathers, bill and feet of birds. Some of the most beautiful pigment colors occur on the inside of certain mollusc shells, where they are never seen until the soft parts of the animal are removed from the shell, and in the Cœlenterata, which are animals that do not possess eyes.

Physical colors give us white when there is a total reflection or metallic color, due to refraction and iridescent color caused by diffraction. The feathers on the neck of a humming bird or a pigeon furnish a good illustration of physical colors.

Under some conditions color fails to develop in an individual, and there is a total lack of color in the hair, as, for example, a white woodchuck, or in the feathers, as in a white robin or a white sparrow. This lack of color is known as albinism and is a condition that occasionally occurs in man, resulting in a pink iris. Such people cannot endure strong sunlight. The opposite condition to albinism is an excessive production of pigment, to which the term melanism is given.

Plasticity of Protoplasm.—One cannot but be impressed with the wide range of change existing in animal structures from the preceding

outline of adaptations. Even the bony skeleton shows that important elements have been either greatly reduced, as in the legs of seals or entirely omitted, as in the hind legs of whales. Usually these changes consist in strengthening certain parts and reducing others, such as the bones in the legs of a horse. In a general way we may designate this range of change in living things as plasticity. Sometimes this term is restricted to the changes that can be induced during the lifetime of an individual, changes which are frequently designated as the modifications or modifiability of parts in an organism. In this use of the term the reference is to the influence of environment upon an individual, such as when an Englishman in foreign service becomes, in the course of half a lifetime of work under a tropical sun, so thoroughly tanned that the browning never disappears even after he has returned to a temperate climate. Whether we use the term plasticity in the broader sense or in a restricted way it is a valuable term to help us to visualize the general concept of adaptation as outlined in this chapter and furnishes a convenient term to describe one of the fundamental characteristics of protoplasm. Adaptation is possible, then, because of the general and universal plasticity in protoplasm.

REFERENCES.

- Jordan and Kellogg: *Evolution and Animal Life*, Chapters XVI to XIX.
Lull: *Organic Evolution*, Chapters XVIII to XXIV.
Morgan: *Evolution and Adaptation*, Chapter I.
Newbegin: *Color in Nature*.
Romanes: *Darwin and after Darwin*, Chapter II.
Scott: *The Theory of Evolution*, Chapter II.

PART V.

THEORETICAL INTERPRETATIONS.

CHAPTER XXII.

THE SCIENTIFIC METHOD.

"ALL writers on the principles of science agree that man has as yet discovered nothing except a little of the order of Nature, and that the reason why events occur in one order rather than another, or even why they occur in any order, is a mystery to which Nature gives us no answer."¹

In this general section on Theoretical Interpretations we place more emphasis upon some of the explanations and theories of living protoplasm than on a study of facts. It is true that you will encounter many facts in this study, but your attention is directed particularly to a group of facts connected with the present form and distribution of life that demands explanation; to the method or rules employed in such explanations; and to an examination of extracts from two of the more important theories of evolution. Whenever we study such theories we are examining the philosophy of evolution, and we should keep clearly in mind the distinction between a study of the facts as such and the explanation of their meaning or the philosophic study of them. Facts cannot be altered or set aside. They exist irrespective of the philosophic explanations of their meaning. The reason that we can speak and write with confidence about so many things in science is due to the painstaking care with which a great multitude of facts have been collected and classified. One of the most grievous offences that a scientific writer can commit is to make false statements about his facts. We must be able to accept them unquestionably. A wide range of latitude is permitted in his explanations but none in the statement of his facts.

¹ William Keith Brooks, for many years Professor of Zoölogy in Johns Hopkins University.

Any attempt to state the fundamental generalizations of a science is beset with many difficulties, the most important of which is our fragmentary knowledge of the whole subject. Biology presents more difficulties than either chemistry or physics, because it deals with more kinds of things, all of which are organized into the most complex structures known. The chemical and physical properties of water, sugar, iron, etc., are elementary in their simplicity in comparison with an ameba. But an ameba is one of the simplest of living things. As we ascend the scale of animal and plant life, complexity takes the place of simplicity. To formulate generalizations that shall be applicable to the more than one million different species of organisms known to biologists represents the highest development of science.

The simple results expressed in the few generalizations that you have learned in this course are the fruit of an enormous amount of work by many investigators. But work alone could never have brought order out of all of the confusion. The work had to be done according to some plan; this plan we know as the scientific method.

When Lyell, in 1830, announced in his *Principles of Geology* that the former changes in the earth's surface could be explained by a study of the causes now in operation, he formulated for the first time the main points in the scientific method. Darwin was one of the first to employ it in biology. Let him tell how he did it: "By collecting all facts which bore in any way on the variation of animals and plants under domestication and nature, some light might perhaps be thrown on the whole subject. My first note-book was opened in July, 1837. I worked on true Baconian principles, and, without any theory, collected facts on a wholesale scale, more especially with respect to domesticated production, by printed inquiries, by conversation with skilful breeders and gardeners, by extensive reading. When I see the list of books of all kinds which I read and abstracted, including whole series of journals and transactions, I am surprised at my own industry. I soon perceived that selection was the keynote of man's success in making useful races of animals and plants. But how selection could be applied to organisms living in a state of nature remained for some time a mystery."¹

After Darwin had worked for about twenty years he was able to classify his numerous observations and formulate his famous theory of the Struggle for Existence. During the past seventy-five years this method of work has dominated science and is responsible in a large measure for the marvelous progress in this field of learning.

¹ The Life and Letters of Charles Darwin, vol. ii, p. 83.

If we separate the scientific method into its parts a clearer notion of how it operates and how we may operate it is obtained. These parts are cause, effect, classification.

1. The scientific method implies that the happenings of today are the outgrowth and continuation of some previous happenings which it is customary to speak of as causes. A metaphysical first cause has no place in the scientific method simply because it is something that is unknown. When a happening is repeatedly found to be associated with an equally constant result it is spoken of as the cause of the result. In the refinements of analysis it is proper to ask why it is a cause, whether it is the only cause or what causes are associated in producing a given result.

2. When a given fact is observed to be a cause, then the one or more happenings which it initiates are designated as effects. There is thus a definite relationship between cause and effect which constitutes the essence of the scientific method. It implies that the results cannot take place without a given cause. When this is applied to our everyday knowledge one says that the leaves appear in their season and that a maple leaf does not grow on an elm tree. Fruit time and harvest are preceded by an orderly series of events, each linked to each as in a chain. This principle is not limited to organic life. The passing street car, the torrential brook in spring time freshets or the destructive tornado are to be understood only after a close study of certain particular causes. To express the same idea in a different way, one may say that every happening, every material thing in the universe of today has had a continuous history. The happenings of today become the history of tomorrow, and it is necessary to know the history of yesterday if one would understand the happenings of today. *The scientific method implies that all observations shall be made in such a way that they can be repeated, controlled¹ and verified by subsequent observers.*

3. Simply to trace the relationship between cause and effect is to stop short, to leave the job incomplete. Nor is the mere collection of a vast number of observations, facts or cause and effect relations, especially helpful unless the next step is taken which is classification. In all of your laboratory study the work has been carefully arranged and you have been guided in your collection of facts. If you will review any one of the laboratory topics you will discover that you collected your facts in an orderly manner. For example, as you

¹ The word "controlled" has a technical meaning referring especially to verified repeated experiments.

described the external parts of *Rana pipiens* the body was divided into head, trunk and limbs, with specific facts to be ascertained in connection with each part. When you had completed this study, you had worked out many of the species characters of *Rana pipiens*. In a similar way the facts about all organisms are classified and order is introduced into man's method of dealing with living things. After the facts have been properly classified and general principles or laws formulated that apply to large numbers of organisms, such as the generalizations that can be stated for all animals with backbones or for all flowering plants, then men can attempt to explain their meaning—to philosophize about them.

Each new fact placed in its proper relation to a larger grouping of facts enables us by so much to anticipate nature, in short sets us free and gives new meaning to the saying "The truth shall make you free." So far as the existence of the accumulated facts and generalizations of science are concerned, they have existed as long as man has lived and many of them much longer. But for early man they were unknown and, so far as he could take advantage of them, non-existent. In the same way they are non-existent for many persons even in this age because they have no actual knowledge of them. The more man comes to understand the relationships existing between antecedent happenings and consequent results the greater is his progress and the more economy he can introduce into his thinking.

We may regard the scientific method as furnishing the rules governing man's attempt to acquire knowledge of Nature and supplying the facts which everyone is required to consider who offers a philosophic explanation of life.

The following four chapters illustrate general problems present in animals and plants, while the fifth chapter shows some of the philosophic attempts to explain them.

CHAPTER XXIII.

THE SIGNIFICANCE OF FOSSILS.

FOSSIL remains of organic life were observed but not understood by the ancient Greeks. It was not until the sixteenth century that the true nature of fossils was surmised. The Italian Leonardo de Vinci has the distinction of first announcing that fossils were the remains of



FIG. 174.—Fossil leaf from a sassafras tree that was common in the cretaceous period.

plants and animals that had once been alive but at an earlier period. In 1669 Steno argued that similar effects are due to like causes and that the conditions that would produce structures like those existing in living animals and plants could have been formed only in organic beings, hence fossils must be the remains of living things.

The next step consisted in comparing fossil remains with living forms which resulted in the conclusion that many fossils belonged to extinct races of animals and plants. As such comparisons were being made it was observed that a given kind of fossil usually occurred in the same strata of rock, which was of great assistance in the identification of the age of rocks in disconnected regions.

Scientists have agreed that all remains or traces of plants and animals that have lived before the present geological period, and that

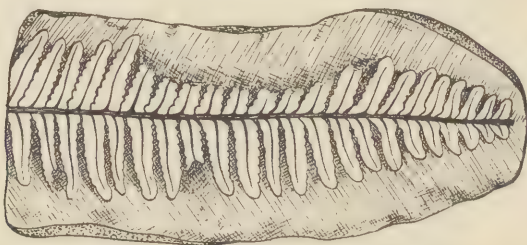


FIG. 175.—Fossil fern from the coal measures (carboniferous period). Do you know any modern ferns that look like this species?

have been preserved in the rocks, are to be regarded as fossils. These remains usually become petrified, *i. e.*; various mineral substances take the place of the organic matter. On the other hand we have carcasses of mammoths entombed in the frozen mud-cliffs of Siberia and insects caught in the amber of gum-trees that are just as truly fossils. Even tracks in the mud, the imprint of a leaf or a shell come under this definition of a fossil.

Animals possessing skeletons in some form, such as either the external skeleton of a crayfish or the internal skeleton of a frog, would be more apt to be preserved as fossils than jelly-fish or earthworms. The life in the seas had a better chance for preservation than the life on land, because land animals would not be covered over before they decayed or were eaten except when caught in peat bog or morass. This is the reason why we know so much less about the life on land as compared with ancient aquatic life.

The kind of rocks in which fossils are found helps us to reconstruct many of the habits of animals. For example, fossils found in sandstone rock were shallow water and shore living animals. These rocks are known to be formed only in shallow water and often show ripple marks. Thus we are able to define the habits of the animals found as fossils in these sandstone rocks as those of animals that must have been living in shallow water and along the shores, and the kind of

food and the methods employed in securing it can be told with confidence in their accuracy.

On the other hand, fossils found in hard limestone rocks tell another story because we are just as certain that such rocks are formed in deep water, possibly in the dark abysses of the ocean. The organic remains in such rocks were mostly free swimmers in the ocean (pelagic) and sank to the bottom after death. Their habits were distinct from those of the animals that were preserved in the sandstone strata.

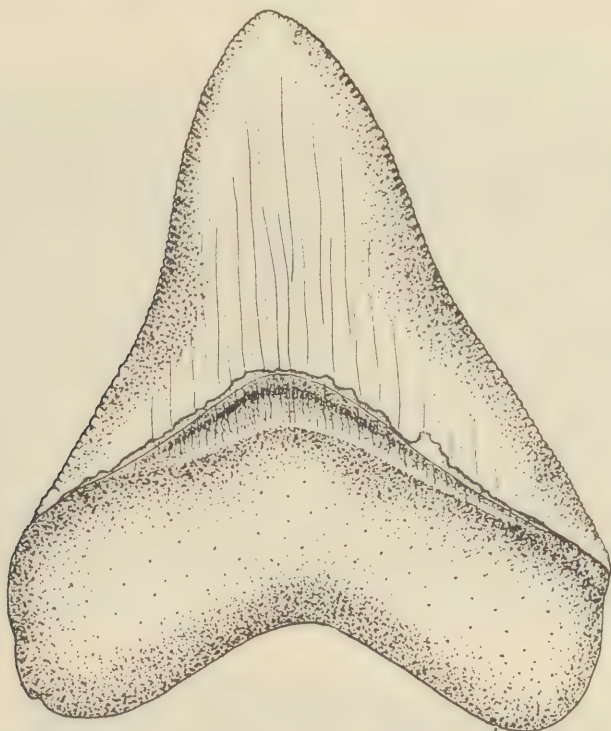


FIG. 176.—Tooth of a fossil shark (*Charcharodon megalodon*) of the tertiary period.
Compare the parts of this tooth with those shown in Fig. 177.

It is not common for the entire skeleton to be preserved in the same place. Tides and waves helped to scatter the many parts over a wide area so that but a few bones are usually found together. Then too the subsequent changes that have taken place in the rocks themselves, especially the large amount of erosion, have often destroyed portions of the rock strata and its contained fossils. The result is that paleon-

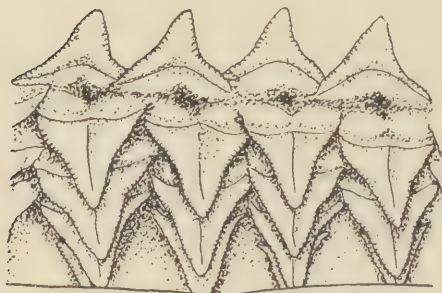


FIG. 177.—Teeth of a recent shark—natural size. Note that they are arranged in successive rows. As soon as those at the top wear down or break the ones in the next row take their place.



FIG. 178.—*Venus mercenaria* fossil on the left and recent on the right. This animal has undergone practically no change during all of modern geologic time.

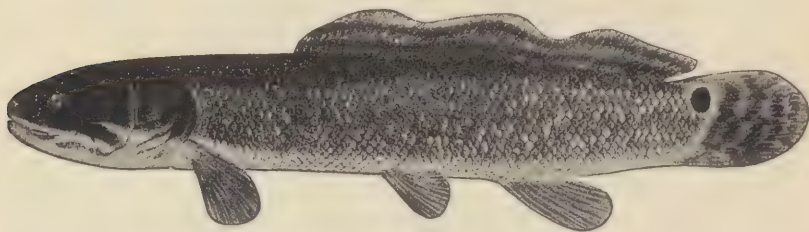


FIG. 179.—Bowfin, a fish that should be a fossil. The bowfin cannot be compared with modern fish because it has no near relatives in this country or in any part of the world. Its next of kin became extinct some millions of years ago during the Mesozoic. The king-crab *Limulus*, the brachiopod *Lingula* and the plants known as scouring rushes, the *Equisetæ*, are additional organisms which have persisted for millions of years without undergoing much modification. It is only by a study of fossils that we have come to know anything about the family history of these several organisms.

tologists have not been able to secure complete records even of individual animals, to say nothing of finding the different species of animals and plants that once lived on land and in the water of prehistoric time.

The most commonly found parts are the teeth and vertebræ of vertebrates while imprints of the shells of molluscs and brachiopods are more frequently encountered from the invertebrates. In one locality a given form of life prevails in the rocks while in another an entirely different species of fossil is more numerous. However, when you visit a museum the entire skeleton of a fossil elephant, horse or



FIG. 180.—Restored model of Piltown skull by Dr. Smith Woodward. The fossil parts are black and the restored parts are white. Do you think that these white parts are correct? (Photograph furnished by American Museum of Natural History.)

dinosaur is shown you. In all such specimens the fossil parts are shown in one color and the manufactured or reconstructed missing parts in another. How is it possible for a man to restore the parts of an animal that he has never seen? In your study of the appendages of the crayfish you made certain comparisons and worked out certain relations. Let us apply what you learned in making these comparisons to the broader aspects of the problem.

Homology.—The similar manner in which the same parts in widely different animals develop enables the expert to detect important

relationships. An examination of any series of vertebrate skeletons indicates that the vertebral column of one contains the same kind of vertebræ as those in all the others. The bones in the arms and legs show the same fundamental number of elements, although variously modified (Fig. 181). The bones in the wing of the bird are like those in the human arm, although there are more bones in the human wrist, but in the embryonic wing the missing bones are present. Some adult organs thus reach their state through a growth from the simple to the

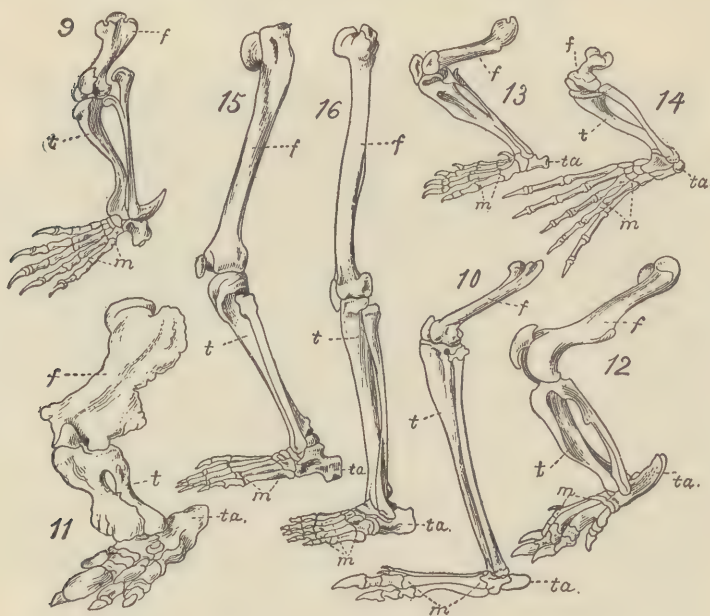


FIG. 181.—Limb skeletons of various animals showing homologous bones: 9, ornithorhynchus; 10, kangaroo; 11, megatherium; 12, armadillo; 13, mole; 14, sealion; 15, gorilla; 16, man. (From Jordan and Kellog.)

complex, and later assume a simpler form. Many other common relations and organs are associated in animals that possess a backbone such as a dorsally placed nervous system containing a neurocele, a ventral coelom containing the organs of digestion, reproduction, etc. But *no matter* how numerous these similarities are, they never amount to identity

No matter how different the general appearance of organs or structures, and *no matter* how different their general function, if they can be shown to have had a common origin, they are said to be homolo-

gous. Homologous organs usually have the same relative position on the animal. This means that organic beings are constructed of corresponding parts and that the main difference between them consists in variations in the original and fixed number of elements. An element may be large in one animal and small in another; simple or complex, as in appendages of crayfish (Fig. 124).

The chief difference in the group of vertebrate animals consists in variations in the number of fixed elements that constitute the typical vertebrate. This study of homology serves to show the relationships in similar and also in some divergent adult morphological structures. The homologies in the family of *Ranidæ*, for example, are very close, because all of the true frogs have sprung from the same stock, while the homologies between fishes and amphibians are more general. So far as it is known homologies never arise in organic nature except through genetic relationship.

The homologies indicated in Fig. 181 deal with the broader aspects of the problems, such as the entire bone in the arm. But the same principle applies to the detailed parts of every bone just as truly, and it is this detailed application of homology which greatly assists the expert in determining relationships.

Scientists who have given a great deal of study to the morphology of living things have noticed that there is a close relationship existing between different parts of the body; for instance, animals with two chambers in the heart always have gills, live in the water, use fins in locomotion and have the body covered with scales. If one finds, then, a tooth of a fish, a vertebra of a fish or fish scales in the rocks he can reconstruct correctly many parts of this animal which man never saw. Again, if the fossil hunter finds three or four vertebrae of an unknown animal he can reconstruct the entire vertebral column.

This same principle is applied in hunting for species of animals that must have been the ancestors of fossil types already discovered. Men become so expert in the application of this principle that they are able to detect a new fossil at a glance.

The application of the principle of homology has yielded splendid results in the attempt to write the history of extinct life and to point out its relation to present day life. We are now able to describe not only the general form of many extinct animals but to indicate their habits of living. Fossil star-fish have been discovered wrapped around fossil clams just as they can be seen today (Figs. 182-183). So complete are the records of some species that the entire embryonic history is known, and in every instance these fossil animals have grown



FIG. 182.—Star-fish photographed in position to pull apart the valves of the clam shell preparatory to eating the soft parts. Compare with Fig. 183. (Photographed by I. A. Field.)



FIG. 183.—Fossil clams and star-fish preserved in such close association as to suggest that the star-fish were feeding on the clams. (From John M. Clark.)

from like animals and have gradually become differentiated into adults. Through these studies we have learned much about the beginnings of some of the great classes of plants and animals, although much remains to be discovered. All fossils can be classified on the basis of their structural relationship just as modern plants and animals are classified. All of the facts thus far accumulated indicate that the fundamental principles of protoplasm applied to fossils in just the same manner in which they are characteristic of modern plants and animals.

The student is expected to read some of the following references in order that he may fill in the outline presented in this chapter:

REFERENCES.

- CRAMPTON: The Doctrine of Evolution, Chapter III.
HUXLEY: The Rise and Progress of Paleontology, Popular Science, 1882, vol. xx.
LOCY: Biology and its Makers, Chapter XV.
LULL: Organic Evolution, Chapter XXV.
ROMANES: Darwin and after Darwin, Chapter V.
SCOTT: The Theory of Evolution, Chapter IV.

CHAPTER XXIV.

GEOGRAPHICAL DISTRIBUTION AND THE MEANING OF COLOR.

THE analysis of the causes which determine the present distribution of organisms on land and in the sea is beset with many difficulties even to those who have given years of study to the problem. For this reason beginning students should be cautious in their generalizations. At all times one must keep in mind the biogenetic law and its implications that not only do all members of a genus but also all members of the great classes or phyla have a common ancestry.

The well-known biological fact of geographical distribution is illustrated by all groups of animals and plants when all of the members of a genus are taken into consideration. In our general studies we are restricted too often to but one species of frog, sparrow, crayfish or trillium with the result that the important biological fact of distribution is wholly unappreciated. The following facts and Figs. 1, 3, 4, 184, 185, taken from some of our most familiar animals, clearly indicate the meaning of geographical distribution.

When one examines the genus *Ranidæ* he finds that the sixteen species in North America have the following living conditions: *Rana pipiens* is the most common frog in North America east of the Sierra Nevada Mountains and is the only frog found between the eastern part of the Great Plains and the Sierra Nevada Mountains. *Rana sylvatica* is a swamp-inhabiting frog in the northeastern part of the United States. *Rana sphenoccephala*, *R. areolata*, *R. æsopus* and *R. grylio* are limited to the States of Georgia, Florida, Mississippi and Texas. *Rana palustris*, *R. clamitans* and *R. catesbiana* are each common throughout eastern North America, including Canada. *Rana onca*, *R. drytonii*, *R. aurora* and *R. boylii* are found only on the pacific slope of the United States and in Utah, Nevada and Oregon. *Rana virgatipes* has been reported only from New Jersey; while *R. cantabrigensis* and *R. septentrionales* are wholly northern species found chiefly in Minnesota, Wisconsin, the Adirondacks and Canada.

The crayfish which you studied belonged to the genus *Cambarus* and the sixty-five species of this genus are never found west of the

Rocky Mountains, while the second American family of crayfish, the genus *Astacus*, contains but five species, all of which are found living west of the Rocky Mountains.

Each of these familiar animals must have migrated from some one place according to the law of biogenesis before they became fixed in



FIG. 184.—*Bufo valliceps*, a Mexican toad. (Photographed by M. C. Dickerson.)

their present habitats. It is also to be noted that such species as *R. pipiens*, *R. palustris*, etc., are able to live under a wider range of environmental conditions than either the southern or western members of this genus. In these examples, selected to introduce us to the



FIG. 185.—*Bufo cognatus cognatus*. Reported from Nebraska, Kansas, Arkansas and Arizona. It is probably found in other States of the Western plains as well as in other of the Rocky Mountain regions. (Photographed by M. C. Dickerson.)

problem of the distribution of animals, temperature would seem to be the main factor or cause that holds these species in their present living conditions.

Frogs and toads have been in existence for a long time, possibly ever since the Devonian geological period. Since that time there

have been many changes in the earth surface of the North American continent and the climate has shifted from a tropical, moist stage to our present North temperate and Arctic zones, with its annually recurrent winters that have forced the Amphibians to take up the hibernating habit. Thus while temperature may be the main barrier that keeps modern frogs and toads from having a universal distribution in the temperate region it is a condition that has not always existed.

Amphibians are not found on the high mountains or in northern Canada because it is too cold for them, nor are they found in the sea or on oceanic islands because they cannot live in salt water. Thus the salinity of the ocean becomes an effective barrier to the migration of frogs from one continent to another or from the mainland to nearby



FIG. 186.—The common "horned toad" of the arid west. (Photographed by A. G. Rutheven.)

islands. Temperature, mountain ranges and bodies of water constitute the great outstanding barriers which prevent indiscriminate migrations of animals at present.

Some writers have mapped North America into zoögeographic realms or divisions, using the isothermal lines to indicate the boundaries such as the Arctic, which includes all land north of the isotherm 32° . In a very general way this is helpful, but fails when applied in detail. There is such a vast difference between the swamp conditions on the one hand and the arid plains on the other, both of which may be in the same temperature belt, that no comparison of the environmental factors is possible, nor can the organisms found in the swamp habitat be transferred to the arid plain conditions (Fig. 186). There is something more fundamental than temperature that determines the present distribution of animals and plants in North America.

The migrations which once took place in the genus *Ranidae* and *Bufonidae* has resulted in the present permanent distribution of these species in North America. It is the conviction of students of organic distribution that the impelling cause of such migrations was a changing climate, an increase in competition for food, a place to live and protection from enemies.

Several prehistoric migrations have been unravelled through a study of the fossils found in regions now separated by barriers such as the general distribution of fossil elephants in Asia and North America from their original home in Africa; or the migrations of camels from North America into Asia and of the llamas (relatives of camels) into South America.

Such migrations are better understood by a study of the seasonal migrations of the modern caribou, seals, salmon, "Rocky Mountain Locust" and birds. The instinct which impels salmon to leave the salt water and ascend the Columbia and Yukon for thousands of miles to lay their eggs and then die; or the unerring accuracy of the seals as they make their journey of fifteen hundred miles so as to arrive at the Pribilof Islands at about the same date each year, helps one to understand how some of the prehistoric migrations may have taken place (Fig. 150).

The preceding paragraphs considered chiefly terrestrial distribution. Another phase of this same subject is the distribution of life in the great bodies of water, both fresh and salt water. Here it is customary to divide all large bodies of water into three regions or realms: (1) Littoral, (2) pelagic, (3) abyssal.

The littoral or shore division consists of the organisms that prefer shallow water, tide pools and coral reefs. This shore fauna and flora is more abundant in species than any other and often every available place is occupied by some form of life. In no place is the keen struggle for a place to live better illustrated (Fig. 187).

The pelagic realm embraces all of the surface waters and is limited to the depth to which sunlight penetrates which is a little over five hundred feet. Storms and waves disturb the surface waters of this division while its lower strata remain relatively calm. Pelagic fish move in schools and are usually powerful swimmers. Multitudes of invertebrates occupy this realm, floating and drifted about by the tides and winds.

The abyssal realm is defined as the area below six hundred feet. This realm is characterized by an entire absence of sunlight; by no movement of the water aside from slow ocean currents; by an average

temperature in the Atlantic of between 37° and 35.6° and by an enormous pressure from surrounding water. At sea level the pressure is fifteen pounds to the square inch, while at six thousand feet it is about one ton to the square inch.



FIG. 187.—Mussel community, showing abundance of life in shallow water. "Actual measurements of the most thrifty beds gave a yield of one and one-half bushels per square yard or seven thousand bushels per acre." (Photograph taken in Menenesha Pond, Martha's Vineyard, not far from Bay Head, by I. A. Field.)

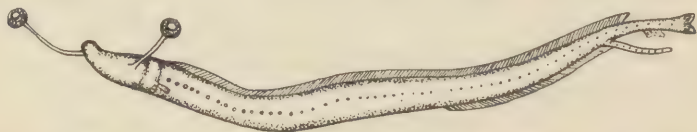


FIG. 188.—"A small, silvery, eel-like fish which has been found in all the oceans at depths ranging from a little less than a mile to two and a half miles. It has a row of luminous pores running the length of the body, and in the blackness of the profound depths it must appear like a miniature long dark boat with gleaming port-holes. Its greenish, glittering eyes are perched on the ends of slender horn-like tentacles—a feature which has suggested its scientific name, "*Stylophthalemus paradoxus*." Re-drawn from Hussakol Amer. Mus. Jour., 1915, xv, 252.

In the abyssal depths are found many fish with odd shaped bodies moving about in complete darkness, except for a dim phosphorescence produced by themselves (Fig. 188).

The animals that have become adapted to one of these distinctive habitats seem to be restricted to it, although there are no actual barriers. There is, however, an intermediate fauna which passes from the littoral over into the pelagic on the one hand or over into the abyssal on the other. Jordan found that the pelagic conditions act as a barrier to shore forms, since certain species of fish along the coast of California are similar to the shore fish about the islands of Hawaii, the open sea being the only barrier keeping them apart.

This outline on geographical distribution aims to help you in stating the general problem of the present distribution of organisms in space. In order to understand their distribution in time, some knowledge of geological history is indispensable.

The distribution of animals and plants in space and time is a study of the end-results of their relations to an environment that has undergone many changes. At present there is no way of computing how many species have become extinct during the many adjustments that each genus has been compelled to make. There would be no problem to solve in this study of the results of migrations were it not for the accepted fact of biogenesis and the rules of interpretation formulated by the scientific method.

MEANING OF COLOR.

With the advent of Darwin's theory of the origin of species by Natural Selection, color came to have a definite meaning. Students of the problem of color then began classifying color according to its possible uses in the life of animals, which has given us the following: Warning colors; terrifying manners; mimicry or protective coloration. Each of these implies that color serves some useful purpose to its possessor. Even these general classes of color are divided until one has sympathetic, alluring, warning, mimetic, signal and recognition, confusing and sexual colors.

Under sympathetic color is grouped the blending of the color of an animal with its surroundings as it hunts or is hunted. The owl and grass snake illustrate this idea as do those animals that undergo a seasonal change of color, such as the white hair of the weasel in winter and its reddish brown in summer. Many of the arctic animals have a winter dress which completely harmonizes with the snow and ice. Several species of spiders have their bodies colored like the flower upon which they rest as they lie in wait for the unwary insect seeking pollen. Some fishes have a modified portion of the

dorsal fin highly colored which they dangle in front of their own mouths. This is interpreted as a lure that assists them in capturing their food.

Conspicuous red and yellow colored animals are usually unpalatable or deadly poisonous, and so these two colors are considered as warning colors. The hornets, the Gila monsters and many caterpillars and butterflies are the usual examples given under this subdivision.



FIG. 189.—Seasonal variation in color of ptarmigan. (Photograph by American Museum of Natural History, New York.)

Any one who has seen a herd of Virginia deer in nature or even in a zoölogical park is at once struck by their habit of showing their "flag" when frightened or injured. The flag is the conspicuous white patch of hair on the under side of the tail and adjacent parts. The tail is raised when the deer is frightened, thus exposing a large white area which is hardly noticeable when the tail is in its natural position. When this large white patch is shown it acts as a signal to the rest of the herd and all flee (Figs. 190, 191).

The colors on fish are often classed as recognition marks. Their dark colored backs conceal them when viewed from above and their light colored bellies prevent their being seen from below. This is

regarded as a phase of sympathetic coloring. But the special color markings on the side of the body, such as the red and orange spot on a brook trout, are classed as recognition marks.



FIG. 190



FIG. 191

FIGS. 190 and 191.—Deer with the “flag” down and with the “flag” up. Note the alert attitude of the entire body when the “flag” is up. Courtesy of the New York Zoölogical Society. (Photographed by E. R. Sanborn.)

When a grasshopper alights we fail to see it unless the eye followed closely the jump or end of the flight. Many moths and butterflies with their brilliant colors are easily seen as long as they remain in flight, but when they alight the disappearance of the bright colors and the blending of the animal with the background confuses us. To this form of coloration we give the name protective (Fig. 191).

Among most of the vertebrates the male is more highly colored than the female, especially during the mating season. Birds furnish the classic examples of such sexual differences in color.

Color is undoubtedly of value to animals. To what extent their protective colors are helpful it is difficult to specify. As the higher types of animals range over a widely varying landscape there cannot



FIG. 192.—Woodcock on the nest, an illustration of protective coloration.
(Photograph by Guy A. Bailey.)

be much protection. On the other hand, if the color actually does partly conceal an animal at such a critical period as during the breeding season then it is of real benefit not only to the individual but to the race. Such colors as have just been described are believed to be preserved in nature by the action of natural selection (page 292).

The benefits derived by animals from possessing a coloration that enables them to be concealed or to secure their food depend on a correspondence in color between the animal and its environment. Mimicry, on the other hand, is a form of resemblance between two different animals. Wallace was one of the first to work out these relationships in any detail, and the following quotation is from him: "This term mimicry has been given to a form of protective resemblance in which one species so closely resembles another in external

form and coloring as to be mistaken for it, although the two may not be really allied and often belong to distinct families or orders." Wallace lays down constant conditions under which mimicry takes place: (1) That the imitative species occur in the same area and occupy the very same station as the imitated. (2) That the imitators are always the more defenceless. (3) That the imitators are always less numerous. (4) That the imitators differ from the bulk of their allies. (5) That the imitation, however minute, is external and visible only, never extending to internal characters or to such as do not affect the external appearance.

The general facts of mimicry are as well established as any phase of coloration in animals. Some of the advocates of mimicry, especially the earlier workers, carried their resemblances too far, as subsequent studies proved, but there is now on record a large amount of valuable evidence in support of the hypothesis of mimicry.

REFERENCES.

- BEDDARD: *Animal Coloration*.
HEILPRIN: *Geographical Distribution of Animals*.
JORDAN and KELLOGG: *Animal Life*, Chapters XIV, XV, XVIII.
LULL: *Organic Evolution*, Chapters IV, V, VI.
NEWBIGIN: *Color in Nature*.
ROMANES: *Darwin and after Darwin*.
SCOTT: *The Theory of Evolution*, Chapter V.
WALLACE: *Darwinism*, Chapters VIII to XII.
WALLACE: *The Geographical Distribution of Animals*.
POULTON: *The Color of Animals*.

CHAPTER XXV.

VARIATION.

Definition.—Variation is used in Biology to describe the differences, structural and physiological, that are always found between offspring and parents. Bateson's comprehensive definition reveals the scope of this topic: "For though, on the whole, the offspring is like the parent or parents, its form is perhaps never identical with theirs but generally differs from it perceptibly and sometimes materially. To this phenomenon, namely, the occurrence of differences between the structures, the instinct or other elements which compose the mechanism of the offspring, and those which were proper to the parent, the name variation has been given."

The following brief review of some common variations aims to establish (1) the fact of variation, (2) the extent with some reference to the kinds, and is based mainly on the organisms with which you have become familiar in the laboratory. With the possible exception of paramecia all of these variations are exclusively limited to differences in the soma or bodily structures.

Variations in Paramecia.—Variations in protozoa have received considerable attention within the past ten years. Here a generation is produced in a day and unlimited numbers of pedigreed stock can be secured for study in a short time. These unicellular organisms have been characterized as essentially free germ cells upon which the environment is directly acting. Jennings finds that paramecia and other protozoa are made up of numerous races, differing minutely but constantly. "The individuals of any race vary much among themselves, but these differences are matters of growth and environment and are not inherited. What is produced in reproduction depends on the fundamental constitution of the race, not on the peculiarities of the individual parent. The fundamental constitution of the race is resistant to all sorts of influences; it changes only in excessively rare instances and for unknown cause. In a study of thousands of individuals of paramecium, through hundreds of generations hardly a single case of such change was observed. Most

differences between individuals are purely temporary and without significance in inheritance; the others are permanent diversities between constant races. Systematic and continued selection is without effect in a pure race, and in a mixture of races its effect consists in isolating the existing races, not in producing anything new." (Jennings.)

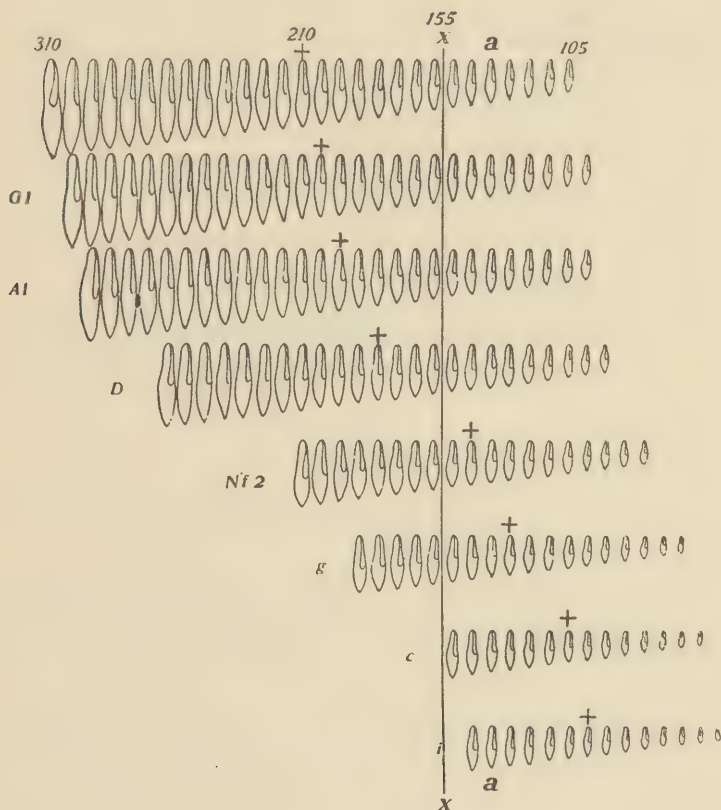


FIG. 193.—Diagram of the species of *paramecium* as made up of eight different races. Each horizontal row represents a single race. The individual showing the mean size in each race is indicated by a cross placed above it. The mean of the entire lot is shown at *x, x*. The numbers show the measurements in microns. The magnification is about 43 diameters. (Jennings.)

Variation in Earthworms.—Pearl has studied 487 earthworms and finds that the range of somites is from 79 to 174, with an average of 142.71 somites, the percentage of variation being 8.31 per cent. The total length of the body ranges from 11.25 to 28.75 cm.,

giving an amount of variation of 16.05 per cent. The length of the earthworm does not depend on the number of somites. In 495 individuals the number of somites anterior to the clitellum ranged from 29 to 32, or 1.41 per cent. variation. The number of somites in the clitellum was from 6 to 8, or 8.02 per cent. variation. With an increase in the number of somites in front of the clitellum there is a marked tendency for the number in the clitellum to decrease.

Variation in Crayfish.—Variations in the crayfish have been extensively studied by Pearl, who made measurements of the length and breadth of the cephalothorax and of the several joints in the walking appendages. The cephalothorax from the tip of the rostrum to the posterior margin on the dorsal median line ranged from 19.2 mm. to 27.2 mm. in the 283 individuals measured. The head breadth ranged from 6.3 mm. to 15.3 mm. There were 50 of the 283 individuals that had a cephalothorax 24.7 mm. long and 58 individuals that had a head breadth of an average of 10.7 mm.

The length of the three distal joints of the first three legs (cheliped and the first two walking legs) was measured. The length of the big claw-joint ranged from 12.1 mm. to 34.1 mm., with 37 individuals averaging 19.6 mm.

The joint next to this one varied from 4.7 mm. to 11.5 mm., with 49 individuals averaging 6.95 mm.

The third joint from the end varied 6.9 mm. to 14.9 mm., with 55 individuals averaging 9.65 mm.

The first walking leg compared with this claw gives the following data: Distal joint, 4.9 mm. to 10.3 mm., with 46 individuals averaging 6.95; second joint, 3.4 mm. to 7.2 mm., with 40 individuals averaging 4.9 mm.; third joint, 5.5 mm. to 11.5 mm., with 49 individuals averaging 7.7 mm.

Sufficient of Pearl's results are given to indicate a considerable range of variation. In the discussion of the paper some of the following important conclusions are formulated:

1. A relatively high degree of morphological differentiation and specialization has associated with it a relatively high degree of variability in the parts concerned.

2. There is no reasonable doubt that the differentiated specialized condition of the leg bearing the great chela is phylogenetically a relatively late acquisition. In other words, it is not a primitive morphological condition. But we find that this part which has been modified most recently phylogenetically is also the most variable of the three appendages studied.

3. The correlation between the homologous segments of the two legs is higher when these two legs belong to contiguous metameres than when they are separated by an intervening metamere.

In all of these illustrations there is (1) a large amount of variation; (2) the variation is continuous and moves in both directions from the normal, *i. e.*, the normal length of the big claw is 14.6 mm., but there are a number of individuals with longer and shorter claws.

The grasshopper bears on the tibia of the jumping leg two rows of spines (Fig. 194), known as the outer and inner rows. These spines vary in number in both sexes, and yet the extent of the variation is constant for each species, which thus affords a distinguishing character in classification.



FIG. 194.—The red-legged locust. *Melanoplus femur-rubrum*, and enlarged hind tibia, showing inner (*i*) and outer (*o*) rows of spines. (Kellogg and Bell.)

In a study of variation some such definite structures as spines are selected which can be measured or counted, and manifestly there are many of these in most organisms. Such parts are technically called "characters." The number of tibial spines, the length of the body and the color markings of the grasshopper are all characters. In a similar way one can select characters in plants, such as the number of petals, length of petiole or subdivisions of the leaf.

Kellogg and Bell¹ collected several lots of grasshoppers and examined the extent of the variation in the tibial spines. In lot 1 there were 39 individuals which had from 9 to 15 tibial spines. Most of the grasshoppers had 12 spines. In order to express graphically the kind and extent of variation the results are arranged in the form of a curve (Fig. 195). The term classes indicates the form that the variation takes, *i. e.*, the tibial spines number 9, 10, 11, 12, etc. The

¹ Studies of Variation in Insects, Proc. Washington Acad. Sci., December 14, 1904, vi, 203-332.

variates are the number of individuals that have 9, 10, 11, 12, etc., tibial spines.

By plotting the results and giving to each variate a definite value and then connecting the several points, a line such as is illustrated in

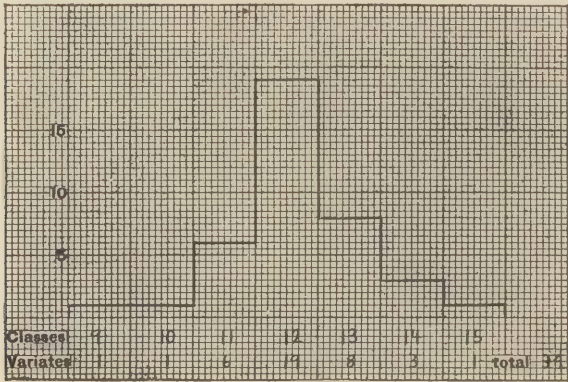


FIG. 195.—Frequency polygon of the variation in number of spines in the outer row of the right tibiae in 39 male red-legged locusts, *Melanoplus femur-rubrum*. (Kellogg and Bell.)

Fig. 195 results. This line is called a frequency polygon or variation curve. In this curve there is one class that has more variates than any other, and for this reason is called the mode or mean class. By

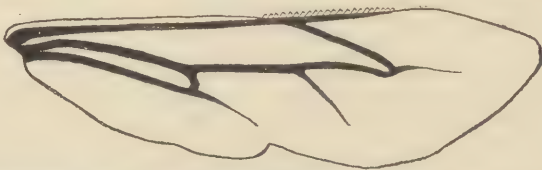


FIG. 196.—Hind wing of honey bee to show position of hooks. (Casteel and Phillips.)

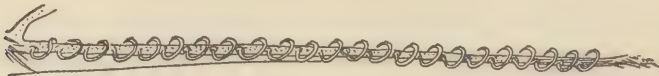


FIG. 197.—Part of the costal margin of hind wing of honey bee much magnified to show hooks. (Kellogg and Bell.)

means of a mathematical formula the exact mean is established and the exact degree of variation from the mean determined

In the frequency polygon in Fig. 195 it is apparent that the range of the number of spines is greater above the mean than below, which

indicates the course of evolutionary movement. These studies can easily be duplicated and plotted in a similar manner while studying the grasshopper in the laboratory.

Variation in Insects.—This class of animals has been extensively studied. The method and results of these studies are illustrated by the following: On the second pair of wings of the worker and drone honey bee are found a number of hooks (Figs. 196 and 197). A study of the hooks in six selected lots of drones and three lots of workers is shown in the following table. The number of hooks is shown at the top and the number of individuals at the bottom (Casteel and Phillips).

HOOKS ON HIND WING.

DRONES.

Classes.	12	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Ave.
I	..	..	..	4	4	8	11	9	4	6	1	1	2	..	..	21.56
II	..	2	1	12	21	23	20	17	2	2	..	..	..	..	..	20.12
III	..	..	..	1	7	12	15	28	14	14	6	2	1	..	..	22.09
IV	..	..	4	10	17	22	27	12	2	5	1	..	..	..	..	20.33
V	..	..	..	4	2	11	10	9	7	1	4	1	..	1	..	21.54
VI	1	..	..	3	3	7	6	23	23	19	6	6	1	..	1	22.42
Variates	1	2	5	34	54	83	89	98	52	47	18	10	4	1	1	

WORKERS.

Classes.	12	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Ave.
I	..	..	..	..	6	9	12	11	6	5	1	..	..	..	..	21.42
II	..	..	..	4	13	42	74	94	61	45	11	4	2	..	..	21.08
III	..	..	..	2	11	18	18	33	8	6	4	..	..	..	..	20.37
Variates	..	..	6	24	66	101	139	80	57	20	5	2				

Variation in *Ranunculus*.—A study of 337 plants of *Ranunculus bulbosus*, which normally has 5 petals, gives the following:

Classes 5—6—7—8—9, number of petals.
 Variates 312—17—4—2—2, number of plants.

Here the variation is in the direction that tends to increase the number of petals.

Methods of Studying Variation.—The accurate study of variation, then, selects a character which can be accurately measured or counted; and the result of such a computation for a large number of individuals is graphically represented in a table or curve. These curves serve at a glance to indicate the extent of the variation, whether it is continuous or discontinuous and the direction in which the variation is moving. Different values are worked out by using certain

mathematical formulæ, which is an attempt to express accurately the extent and significance of variation. This method has given rise to the "biometrician" school, whose exact work has done much to clear up the indefiniteness of biological description. There are many biologists, however, who hold that living protoplasm cannot be measured in millimeters and that a measurement only partly describes. Much skill is required in selecting the so-called characters in the study of variation. At present there is a vast amount of data that has been collected in variation that helps to a better understanding of living protoplasm, because this method of study emphasizes many facts that were previously overlooked.

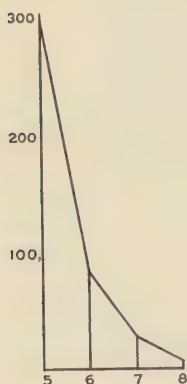


FIG. 198.—"Half-curve" representing the number of "petals" on 416 flowers of the marsh marigold (*Caltha palustris*). (From Doncaster after De Vries.)

Now that we have examined the fact of variation which is to be regarded as a fundamental characteristic of protoplasm in just the same sense that metabolism is, it is desirable to point out the nature of these variations; in short, their significance. It is necessary to keep in mind the important fact that these variations belong to the soma and are the structures upon which Darwin assumed natural selection to operate (page 292). Students of variation have come to the conclusion that these differences in size, number of spines, etc., are not to be explained as alternations leading to some definite change, as in the formation of a new species, but rather to be understood as permanent diversities of paramecium, the crayfish or earthworm in its present environmental relations. That there is a certain range

of variation in the structures found in any given species is common experience, but so far as we have observed, the various species do not appear to be undergoing either progressive or retrogressive modifications. They have, for the most part, become stable or fixed, each having its own characteristic form of variation.

Such is the interpretation of those who hold that the germplasm is the exclusive source of variation. After we have presented the subject of heredity we shall return to a further consideration of variation.

CHAPTER XXVI.

HEREDITY.

HEREDITY is the name for one aspect of protoplasmic activity. As has already been pointed out, one should know as much as possible of the structural conditions and physiological activities. Now we attempt to learn something of the history or inheritance of protoplasm, and we shall see that protoplasm is more than so many chemical elements with a certain physical appearance, it is a part of the past influencing the activities of the present.

Heredity is thus a general term in biology which is used to describe the repetition of parental characters in offspring, and so it is customary to say that the child inherits from its parents or that it has such and such a parental inheritance. The same terms are used in the transmission of property from parent to child, but there is this distinction, that the property is the same in each instance while the biological inheritance is a figure of speech. All of the parental characters are never fully reproduced in the offspring, and this fact causes many of the variations described above.

Scientists are aiming to discover the method by means of which the parental characters are made to reappear in the offspring. The investigations of this problem fall into, first, those who believe that the secret will be discovered in a study of variations; and second, those who seek it in the detailed relations that exist between the chromosomes in fertilization.

Heredity is everywhere present in organic life and serves to transmit not only useful likenesses but many that never mature or are rudimentary. Wiedersheim has reported that there are 180 vestigial organs in man alone. No system of organs is free from them; the skeleton, the muscles, the nervous and digestive systems all have structures that are important to some of the lower vertebrates. The vestigial structures serve to illustrate the hold that heredity seems to have on living matter. Someone has characterized heredity as "organic memory," but this is only suggestive, for mammalian organisms are reproducing with remarkable fidelity ancient ancestral structures of the Devonian geological period, which

extends back in time beyond the reckoning of man. The formation of an embryonic notochord and of gill-slits illustrates this point. Heredity can thus be relied upon to produce ancestral structures, both good and bad, a fact of organic life always to be reckoned with. In this general sense the main hereditary picture of most living things has been fixed for thousands of years. The modern study of heredity, however, is mainly confined to the smaller changes described as Variations, page 262.

Heredity and the Cell.—Whatever may be the ultimate analysis of the problem of heredity, there need be no hesitation in stating that the transmitted characters exist potentially in the protoplasm of the cell. From the egg of a robin only a robin will develop, from the ovum of an oak only an oak will grow, and during growth each

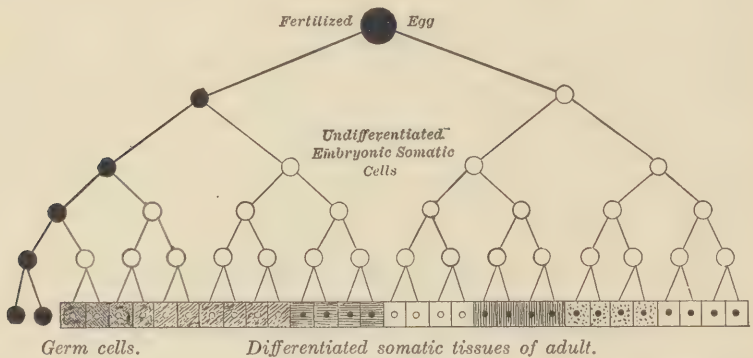


FIG. 199.—Schema of germ and somatic cell differentiation. (After Klebs.)

follows its own successive embryological stages even to the minutest details. It has been well said, "Nature never yet made two eggs or two sperms exactly alike."¹ The cells which give rise to new organisms are the germ cells, sperms and ova. These differ greatly in shape and size. It has been estimated that the volume of the human sperm is not over 50 cubic micra, while that of the human ovum is 1,767,150 cubic micra or over 35,000 times the volume of the sperm cell. The difference in volume between the sperm and ovum of the frog is more than 6 times as much as in man. But notwithstanding this disparity between male and female germ cells it is well known that the paternal and maternal characters are about equally distributed in any population as a whole.

¹ The Basis of Individuality in Organisms from the Standpoint of Cytology and Embryology. By Professor Edwin G. Conklin, Science, 1916, p. 523.

As has already been explained (page 74) the egg cell passes through a period of preparation for fertilization which is known as maturation. During these changes the chromatin undergoes a rearrangement which results in both a qualitative and quantitative elimination of chromatin.

This is a complicated process which is diagrammatically illustrated in Fig. 200. The circles are the nuclei of the cells. Each contains four chromosomes, which is the exact number in the parasitic thread-worm, *Ascaris*. The primordial germ cells divide many times in a regular manner and distribute the chromatin in equal amounts to the forming cells. This stage is termed the oögonia in the case of the cells that mature into ova, and spermatogonia in the cells that are to become sperms. After a time this stage is followed by one in

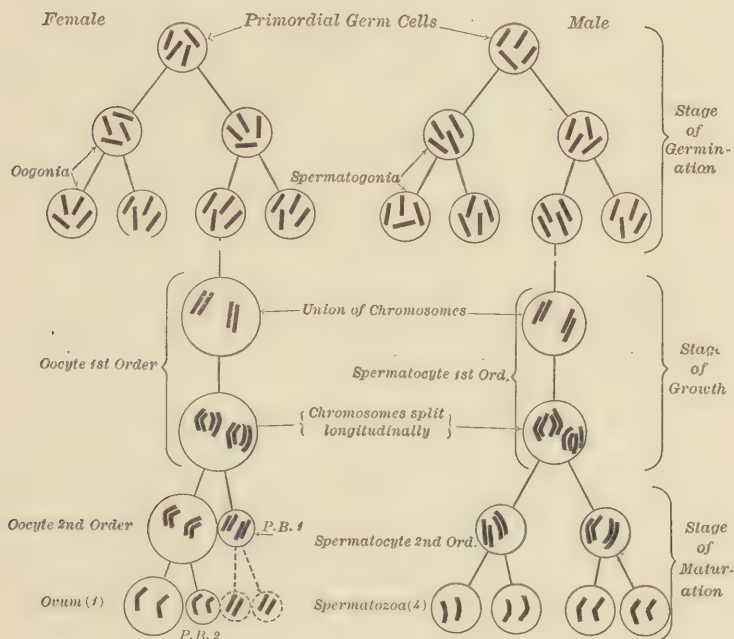


FIG. 200

which the chromosomes fuse in pairs to split later longitudinally, and this stage of growth is termed the oöcyte or spermatocyte of the first order respectively. There is no division of the cytoplasm accompanying this growth change. Now the germ cells pass through

a period of maturation. The ovum forms a polar cell that contains one-half of each of the four chromosomes which have divided transversely. This polar cell later divides. The egg chromosomes do not form into a nucleus following the formation of the first polar cell but immediately separate into two groups, one-half of the number of chromosomes remaining in the ovum, one-half passing into the second polar cell. In this last change there is a qualitative separation of the chromosomes because two whole chromosomes pass out into a polar cell.

The changes in the chromosomes in the spermatocyte are similar except that each of the four cells resulting from maturation gives rise to mature sperms, while in the ovum the three polar cells degenerate.

In the germ cells of most animals the number of chromosomes is many more than the four found in *Ascaris*, but the principle does not change with this increase in number.

The ovum and sperm are now said to be mature. Before maturation the ovum cannot be fertilized, although the sperm may enter the cytoplasm. After the sperm head enters the ovum it is transformed gradually into a nucleus containing two chromosomes (Plate I, 6), and is now designated as the male pronucleus, while the egg nucleus is termed the female pronucleus. As each of these two pronuclei contains two chromosomes, there are now four in the ovum, which is the normal number of *Ascaris*, but each two chromosomes are contained in a nucleus. In order that fertilization may take place the nuclear wall must break down and thus allow the two sets of chromosomes to come together.

Fertilization is the union of the male chromatin (chromosomes) and the female chromatin, but it is readily understood that the repeating of this process generation after generation would serve to accumulate not only a large amount but a vast number of individual chromosomes were it not for this preparatory reduction in maturation. The number of chromosomes in the developing cells of an organism is therefore the same as those of each parent and not double the number.

The number of chromosomes or even the particles of chromatin are relatively small as compared with the number of structural and physiological characteristics of an organism, so that we may not assign to each of these bodies the exclusive responsibility of reproducing a given adult character. The present idea is rather that each chromosome is a complex body, varying in shape (Fig. 201), which

contains a varying number of "genes"¹ (hypothetical bodies), which have the potential power under appropriate conditions of causing the developing cells to take on a given form. This does not mean that the chromosome or the germ cell is a miniature adult that simply unfolds, but rather that the initial or determining cause is

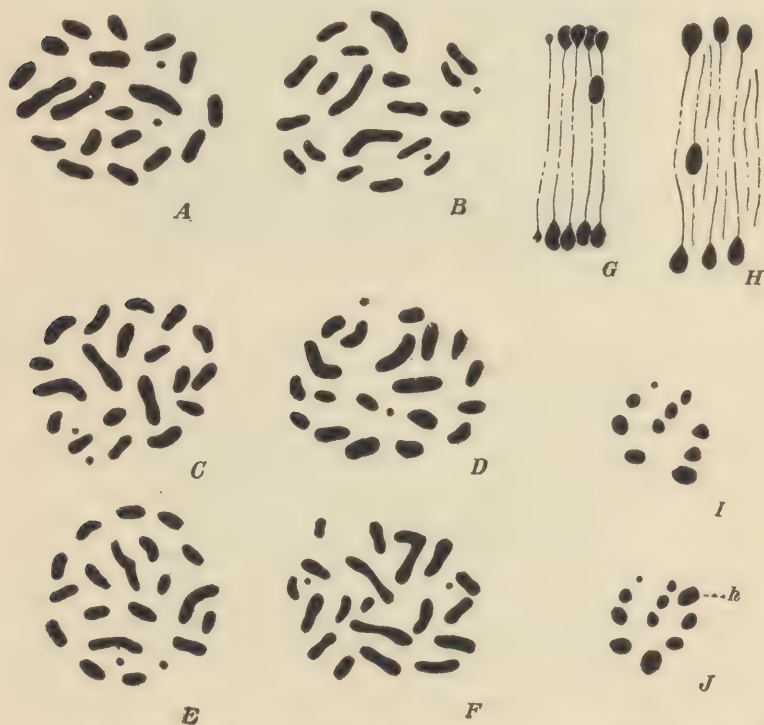


FIG. 201.—Figure to show variation in shape and size of the chromosomes. *Anasa tristis*. A to F, spermatogonial groups; G, H, anaphases of second division, showing division of *m*-chromosomes in G, and the undivided heterotropic chromosome on both spindles; I, J, anaphase groups from the same spindle, polar view, second division, showing *m*-chromosome and macrochromosome in each and the heterotropic (*h*) in J. While each species has a given number of chromosomes, they are not identical in shape and size. (After Le Fevre and McGill, in *Biological Bulletin*.)

in the germ cell and that the full expression of characters comes through a continuous series of developmental stages which is determined by the relation of the genes in the fertilized egg cell.

The cells of the body are divided into body plasm or soma and the germ plasm. Weismann restricted the germ plasm to the nucleus

¹ Morgan: *Physical Basis of Heredity*, Chapter XIX.

of germ cells, in short to the chromosomes. Some writers hold that the cytoplasm also plays an important part in heredity, but all agree that the male and female chromosomes supply the detailed characteristics of each species. After the germ plasm has given rise to an individual a portion of it is left behind which participates in the formation of new offspring, and as Davenport phrases it, "There really is no inheritance from parent to child, but parent and child resemble each other because they are derived from the same germ plasm, they are chips from the same old block; and the son is the half-brother to his father by another mother."

In any such study one should always keep in mind the fact that the chromosomes grow and increase in volume just as the other parts of the cell grow. Were it not for this growth in the chromosomes it would be inconceivable how such a small amount of substance could produce such definite results. This relation is emphasized by the estimate of Parker, who states that the chromosomes in the human ovum weigh about 0.000004 milligram. This makes the weight of the hereditary determining material to the average weight of a man as 1 to 16,250,000,000,000.

Mendelism.—The Augustine monk, Gregor Johann Mendel, published, in 1865, the results of his studies on the pedigree culture of peas, in which he announced an important theory of heredity.

This theory points out three important facts: (1) That the parental characters reappear in the offspring as unit characters, and (2) that one character usually is so prominent that it completely obscures or prevents the other from appearing, it is said to dominate the weaker character; (3) that the unit characters are segregated. These three ideas are readily observed in Figs. 202 to 205. Here a white and a black guinea-pig are crossed and the first generation is all black. These offspring are called the hybrid generation and the black color completely dominates over the white. The white color is not lost, as the subsequent breeding experiments prove. Now as these hybrid black guinea-pigs are allowed to interbreed, definite results follow which are illustrated in Fig. 205. Three of the second generation of hybrids are black and one is white. As both of the parents are black the white color must have existed in the germ plasm, although the parents gave no evidence of being partly white. Specific terms are used to describe these facts of heredity. The black color is said to be dominant over the white and the white color is recessive to the black. Black and white are unit characters. The second generalization is a theoretical inference drawn from the dominant and recessive relation-

ships of such unit characters as black and white. In order that the white color shall reappear in the second hybrid generation, the hereditary determiner for white must have been present in the first



FIG. 202.—An albino male guinea-pig, father of the black young shown in Fig. 203.
(After Castle.)

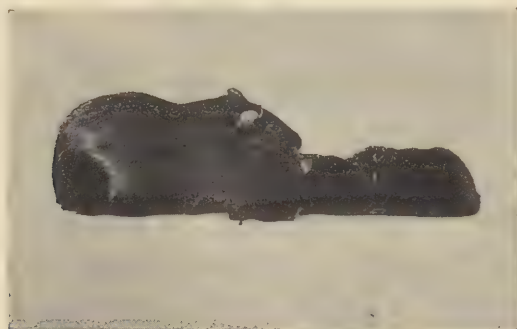


FIG. 203.—A female guinea-pig and her young sired by the albino in Fig. 202.
(After Castle.)

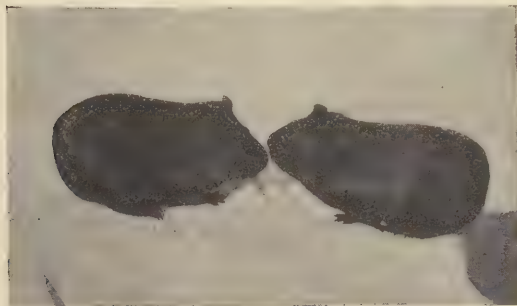


FIG. 204.—Two of the grown-up young of the litter shown in Fig. 203.

generation of black hybrids and remained uninfluenced by its association with the hereditary determiner for black. This is known as the



FIG. 205.—A group of four young produced by the pair in Fig. 204. Note the reappearance of the white in a one-fourth ratio.

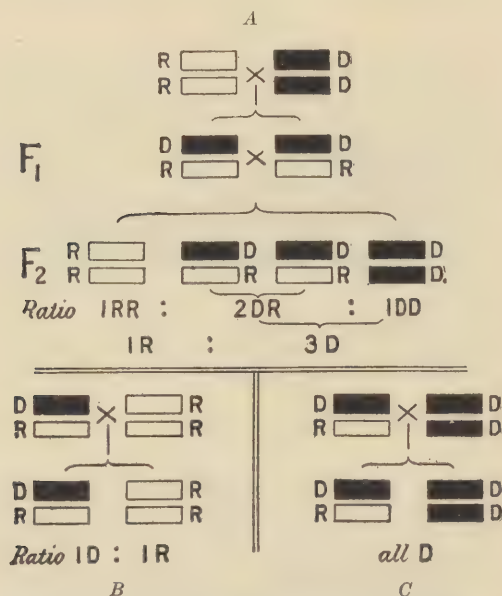
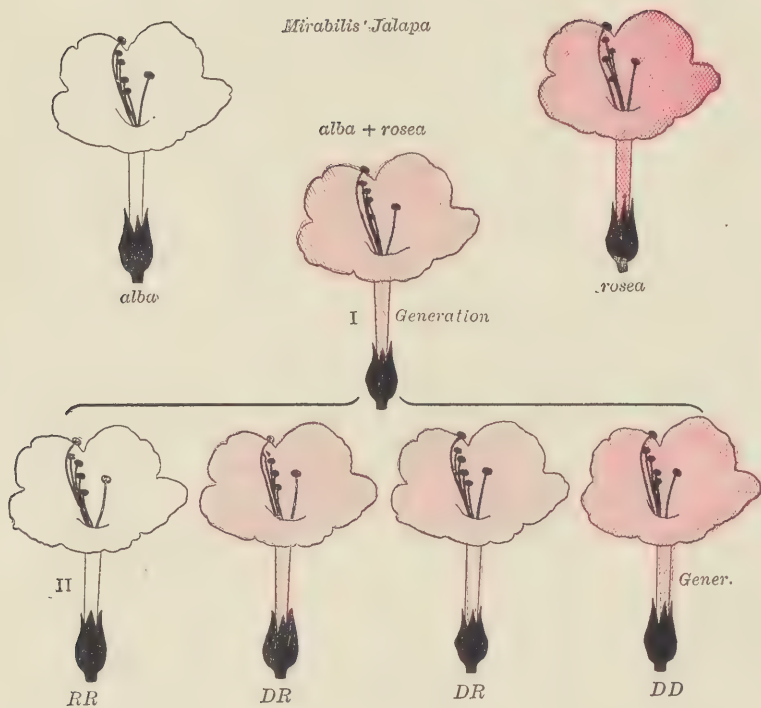


FIG. 206.—Schema of Mendel's law for a single pair of "antagonistic" properties. A, the results of hybridization of a pure dominant (*D*) with a pure recessive (*R*) form; B, the results of crossing a hybrid with a recessive form: 50 per cent. of progeny pure recessive, 50 per cent. hybrid (but apparently dominant); C, the result of crossing a hybrid with a dominant form; all apparently dominant (but 50 per cent. pure, 50 hybrid). (Bateson.)

purity of the germ cells, which means that the determiners for both black and white do not occur in all the germ cells. The white guinea-

PLATE III

Mirabilis Jalapa



pigs of the second hybrid generation when crossed with white guinea-pigs will give rise to white guinea-pigs only. The same result follows with part of the black, while some of the black continue to give offspring that are white and black. This latter condition is diagrammatically shown in Fig. 206, and the reason that there is one white to three black is explained. Pure dominants and pure recessives result when both the sperm and ovum contain black determiners and white determiners respectively. There are other important results which recent students of heredity have discovered and other theories than Mendelism, which are fully discussed in the references at the close of this chapter. Mendelism has been reviewed in this chapter in preference to other theories, because at present it seems to explain a larger proportion of facts.

The common garden four o'clock shown in Plate III produces a white and red flower. When these flowers are crossed the hybrid is pink (I generation). Here the color of the hybrid flower is intermediate between the white and red, and neither color is dominant. By self-fertilizing the hybrid generation, in I generation, the flowers are in the proportion of one white, two pink and one red. This experiment enables one to select the hybrid forms from the white and red and the three classes are readily recognized. Again, consulting the scheme shown in Fig. 206 you will discover that the same explanation is true for this plant as in the guinea-pig.

The unit characters which are now generally accepted by geneticists have in some cases a general distribution in the organism. "Tall and dwarf habits are diffuse characters of the plant as a whole. Hairiness may be on stem, leaves, calyx, part or all of them. Mendelian hereditary units are not leaves, petioles, stamens, etc., but qualities of these organs or still more diffuse qualities of the whole plant." (Harper.) Even the chemical composition of the food stored in corn acts as a unit character, Figs. 207 to 209. In the same sense human stature, temperamental vigor or resistance to disease are unit characters that are inherited and are qualities which are a part of the whole body. Heredity is to be looked on as determining the character of the cells, as those in the skin or muscles, and as formulating the qualities of the organism as a whole.

According to the cytologists, heredity means the normal combination of the chromosomes, although some are willing to admit that the rest of the cell may play an important part. The more deeply one studies into the problem the more difficult it becomes to formulate a definite hypothesis. The recognition that characters

behave as units in heredity has served to add a new avenue of study, with the result that breeders in particular are able to select more successfully than ever before the characters that they wish to emphasize. But the whole story is not so simple, for some of the unit

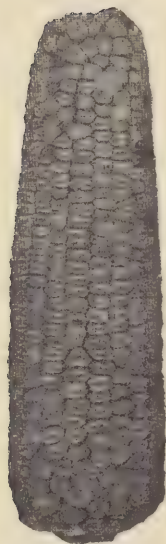


FIG. 207



FIG. 208

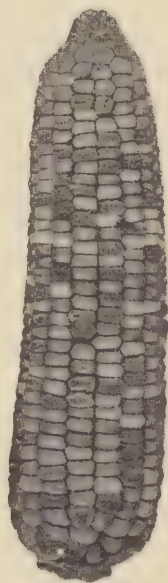


FIG. 209

FIGS. 207, 208 and 209.—Showing Mendelian inheritance in maize. Fig. 207, pure sweet parent race; Fig. 208, pure dent parent race; Fig. 209, ear bearing F_2 progeny kernels from the cross of Figs. 207 with 208. The ears bearing F_1 progeny kernels are indistinguishable in appearance from the pure dent parent ears (Fig. 208). In general it may be said the F_1 kernels resemble most closely the dent parent in their chemical characters. In other words there is a definite tendency toward the complete dominance of the chemical conditions found in the dent parent over those found in the sweet parent. This dominance is by no means perfect in all characters, however. In particular the F_1 kernels are plainly intermediate between the two parents in respect to sugar content. The F_1 kernels in these experiments are not to be told by visual examination from the pure dent parent, yet a chemical analysis shows that they really are different. (Pearl and Bartlett.)

characters are associated in pairs, as it were, and some of the characters, like skin color, for example, are now known to depend upon a number of determiners.

“There are, however, instances in which it appears that Mendelian segregation may not be perfect. It has been maintained that an

instance of this is provided by hair-length in guinea-pigs. When a long-haired ('Angora') guinea-pig is mated with a short-haired, the F_1 offspring are short-haired; shortness being dominant, owing perhaps to the presence of a factor which prevents the growth of the hair after reaching a certain length. But when such F_1 (heterozygous) short-hairs were mated together, in addition to apparently pure longs and shorts, animals with hair of intermediate length were produced, and these crossed back with pure long hairs gave no short-haired young. It is suggested that the long and short characters have become fused in some germ cells, segregation being incomplete or non-existent, so that germ cells bearing the mixed character are produced. Again, in a cross between lop-eared and short-eared rabbits, young with ears of intermediate length are produced, and these mated together give no evidence of segregation in the next generation. From these and some other similar observations it must be concluded either that in some cases there is incomplete segregation or even complete fusion of alternative characters, or that what appear to be simple characters are really complex, and that the true-breeding intermediates are formed by a new combination of elementary factors." (Doncaster.)

An illustration of the practical value of what may seem to some an academic discussion is seen in the testing out of the theory of unit characters as follows: "Some valuable wheats are liable to the attacks of a fungus giving rise to the disease called 'rust,' other less valuable races are immune. Biffen has found that by crossing the two races together, fertilizing the hybrids (F_1) among themselves and selecting the homozygous plants in the F_2 generation, wheat can be produced which combines the valuable features of one race with the immunity to rust of the other, and so a new and most useful variety of wheat is produced."

Some characters are transmitted according to their relation to the sex of the parent. This phase of inheritance is clearly presented in Figs. 210 to 216, where the inheritance of the barred color of the feathers is transmitted only through the male. This is commonly described as sex-linked inheritance.

The tendency at present is to fix the attention upon some character and observe its behavior in heredity. Francis Galton first recognized that there is a tendency for certain characters of the parents to blend in the offspring while others are alternative. When the brown-coated, lop-eared rabbit is crossed with an albino, short-eared Angora rabbit the offspring has ears of intermediate size, which



FIG. 210.—Pure bred barred Plymouth Rock. ♂



FIG. 211.—Pure bred Cornish Indian game. ♀

If one mates the cross-barred Plymouth Rocks ♂ × Cornish Indian game ♀ he gets only barred birds. (Pearl and Surface.)



FIG. 212.—Pure bred Cornish Indian game. ♂



FIG. 213.—Pure bred barred Plymouth Rock. ♀

If one mates Cornish Indian game ♂ × barred Plymouth Rock, all the male offspring will be barred and the female will be black. (Pearl and Surface.)



FIG. 214.—Barred F_1 hybrid ♂.



FIG. 215.—Barred F_1 hybrid ♀.



FIG. 216.—Non-barred (solid black) F_1 hybrid. ♀.

FIGS. 210 to 216 show that barring of the feathers is inherited in a sex-limited fashion. The barred pattern is inherited as a unit character and there is no evidence of a blended inheritance of degrees of intensity of pigmentation. No more striking evidence of the segregation and particulate behavior of characters as units in inheritance can be found anywhere. (Pearl and Surface.)

sometimes stand erect and sometimes lop. The hair of the offspring in the above cross was short and black, the long white hair did not appear but where these black hybrids were bred the parental characters reappeared in their offspring in a definite proportion.

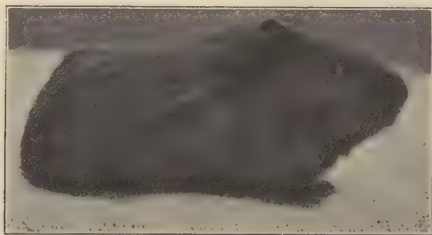


FIG. 217

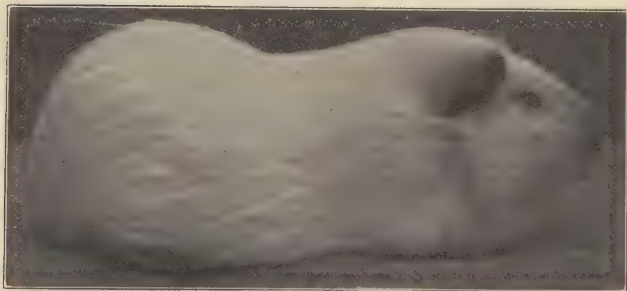


FIG. 218

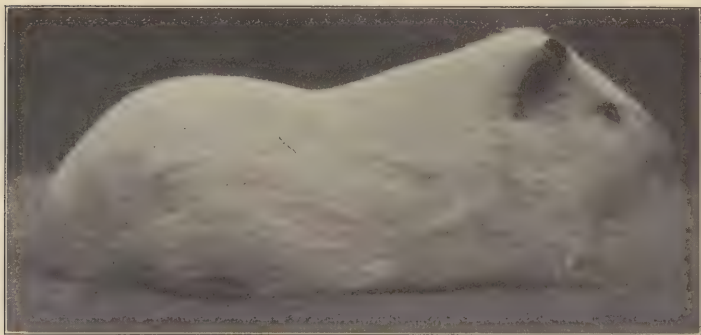


FIG. 219

FIGS. 217, 218 and 219.—Fig. 217, a young black guinea-pig, about three weeks old. Ovaries taken from an animal like this were transplanted into the albino shown in Fig. 218. Fig. 218, an albino female guinea-pig. Its ovaries were removed and in their place were introduced ovaries from a black guinea-pig (Fig. 217). Fig. 219, an albino male guinea-pig, which was mated with the albino shown in Fig. 217. (Description and figures from W. E. Castle.)

“The effect of crossing a pigmented rabbit with an albino is similar to that produced when two pieces of glass, one transparent, the other opaque, are held up together. We see only the opaque one. Nevertheless the two conditions have not blended; each retains its original

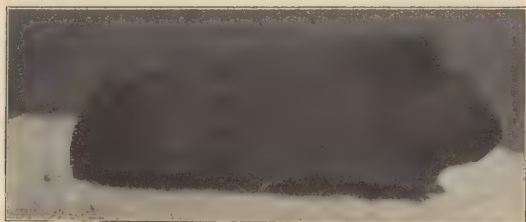


FIG. 220



FIG. 221



FIG. 222

FIGS. 220, 221 and 222 are pictures of three living guinea-pigs, all of which were produced by the pair of albinos in Figs. 218 and 219. From evidence such as this it is concluded that the inheritance cannot be affected by modifications of the body of the parent, not even when the body is completely changed, since the body so far as heredity is concerned is merely a container of the reproductive cells. To modify the inheritance we must modify the reproductive cells. (Description and figures from W. E. Castle.)

distinctness and the two can be separated again at will. So it is in the Belgian produced by cross-breeding with an albino. The albino character is there, though unseen, and will appear as a distinct entity when the cross-breed reproduces, for it will be represented in approximately half of the sex cells formed by the cross-bred animals, the alternative or Belgian character being represented in the other half. It is as if the two pieces of glass, combined originally to illustrate the formation of a cross-bred animal, were separated again to illustrate the formation of the reproductive elements by the cross-bred. For every element formed having the opaque character there will be another having the transparent character, but there will be no elements of an intermediate nature." (Castle.)



FIG. 223.—Hybrid fowl which is a cross between guinea hen and game-cock, showing in an interesting manner the distinctive color of both parents. This is a form of Mosaic inheritance. (Bred and photographed by Dr. Raymond Pearl.)

For a long time men have been trying to solve the question of the inheritance of acquired characters. "Unproved" still remains the best answer, although there are some facts that tend to show that the germ cells can be influenced through the soma or body of the parent.

For many centuries the Chinese bound the feet of their women, but this did not result in modifying the feet of Chinese babies who continued to be born with normal feet. Several scientists have tried removing for many generations of a given animal some such structure as the tail to determine whether the animal would eventually

grow a shortened tail. It is the common practice of sheep-breeders to remove the tail; this is always the custom with certain breeds of horses and dogs, but there has been no appreciable shortening of the tail in succeeding generations.

The brilliant experiment of Castle shown in Figs. 217 to 222, is one of the most crucial tests thus far devised and successfully executed. If the soma cells can produce modifications in the germ cells, then transferring the germ cells from one animal to another would enable a different set of soma cells to nourish them. The results shown in Figs. 220 to 222 indicate that the hereditary factors that are responsible for the black color were not modified by the soma cells of the albino foster-parent.

If the extreme position advocated by those who claim that the germplasm is the exclusive source of variation is accepted, then there can be no progressive variation, for the range of all such variation is limited by the combination of characters derived from parents, grandparents, etc. When one takes a broad survey of organic structures, progressive modification is one of the most apparent facts, as the skull and many other parts of vertebrates clearly indicate. The germplasm advocates of variation hold that mutation, the combination of germplasm factors which result in producing a distinctly different individual by changing many characters at once, explains most of these differences.

On the other hand Castle points out that the color of the hair of the domestic varieties of cavy is more distinct and clear than in wild forms. "For example it is possible by crosses to obtain from wild cavy the retrogressive varieties, black and yellow. But such synthetic blacks lack the full intensity of blackness found in our best strains of black guinea-pigs, and the synthetic yellows are apt to be either pale or muddy in yellowness, lacking the intensity and brilliancy of our best domestic varieties. It is impossible to escape the impression that our improved domestic varieties are not mere factorial recombinations derived from wild species, but that they have been forced up to a higher standard by repeated selection; that the breeder, for example, has first observed variation in intensity of blackness among his blacks (doubtless obtained originally from a retrogressive sport) and that by repeatedly selecting the blackest available individuals he has increased the blackness of the race. Thus it is no accident that the meat and milk and wool-producing capacity of our domestic animals far exceeds that of any wild ancestral species. The standard in each case has been raised and it has not been raised

by a single lucky accident (the mutation view), but by a series of slow advances each impossible until a previous advance had been made."

The discussion of the nature of variation just quoted from Castle and as presented at the close of the chapter on variation introduces you to the two main opinions held by present-day biologists. Before one can formulate the broad outlines of evolution, it is necessary to determine the nature of variation.

Jennings concludes a recent discussion of changes in hereditary characters as follows: "Evolution according to the typical Darwinian scheme, through the occurrence of many small variations and their guidance by natural selection, is perfectly consistent with what experimental and paleontological studies show us; to me it appears more consistent with the data than does any other theory."

The principles of heredity presented in this chapter apply to all organisms and in particular those that reproduce sexually. A number of writers have elaborated these principles in their application to man under the name of *eugenics*, *being well born*, etc. You will be able now to read intelligently these important books because you have gained some understanding of the fundamental principles of heredity in all living things.

For the discussion of latency, atavism, prepotency, origin of sex and other equally important and interesting phases of heredity, the student is referred to the many elaborate works on heredity.

REFERENCES.

- BATESON, W.: Mendel's Principles of Heredity.
 CASTLE: Genetics and Eugenics.
 CASTLE, W. E.: Heredity.
 CASTLE, COULTER, DAVENPORT, EAST LAWAR: Heredity and Eugenics.
 CONKLIN: Heredity and Environment.
 CONKLIN: The Mechanism of Evolution in the Light of Heredity and Development, Scientific Monthly, 1919, ix, 481.
 DARBISHIRE, A. B.: Breeding and the Mendelian Discovery.
 DAVENPORT: Heredity in Relation to Eugenics.
 GUYER: Being Well-born.
 JENNINGS: Observed Changes in Heredity in Relation to Evolution, Jour. Washington Acad. Sc., 1917, vii, 281.
 LILLIE, FRANK R.: History of the Fertilization Problem, Science, January 4, 1916, p. 39.
 MORGAN: Physical Basis of Heredity.
 MORGAN, T. H.: Heredity and Sex.
 PUNNETT, R. C.: Mendelism.
 REID, G. A.: The Laws of Heredity.
 THOMPSON, I. A.: Heredity.
 WOOD, F. A.: Heredity and Royalty.
 WALTER: Genetics.

CHAPTER XXVII.

EVOLUTION.

THE philosophy of organic evolution is chiefly concerned with the manner in which animals and plants have arisen through descent with modifications. While this idea was suggested by the ancient Greeks, it was not until Darwin's contribution, *The Origin of Species*, in 1859 that this conception of the formation of new species began to receive general credence. The idea of the origin of species through the modification of preëxisting species has come to be accepted by all modern students of biology and furnishes the basis for much of our present-day thinking.

What are some of the facts and reasons which all men who try to explain the meaning and origin of the million and more of organic species take into consideration?

1. The fact that all of these numerous species have a number of characteristics in common. (Chapter XI.)

2. The wide range of adaptability in living things which permits structures to assume varied shapes and sizes and which leads to profound modifications of structure and habit. (Part IV.)

3. The study of fossils which reveals the important fact that the same general habits and conditions found in life today have always obtained and that there is a direct continuity between the life of the past and the life of the present. (Chapter XXIII.)

4. The present distribution of animals and plants which is the result of migrations, the only explanation in harmony with the law of biogenesis. (Chapter XXIV.)

5. The universal tendency for living things to vary which is the beginning of the numerous structural and physiological adaptations so abundant in organisms. (Chapter XXV.)

6. All these numerous facts just summarized play a part in heredity where we find a fundamental uniformity in the physical basis (chromatin) of transmission of characters from parent to offspring in all organisms. (Chapter XXVI.)

Embryology.—The manner in which all living things develop, particularly the higher types, furnishes one of the most conclusive

reasons for believing in the origin of species by descent. In the study of the embryology of *Rana pipiens*, we found the segmentation of the embryo proceeding from the simple to the complex until definite germ layers were formed. These germ layers in turn through natural growth changes gave rise to the several organ systems found in the tadpole. The tadpole represented a stage intermediate between the

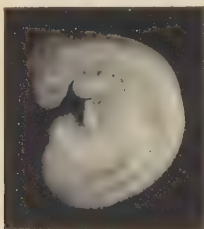


FIG. 224.—Photograph of a 4 mm. human embryo. Gill-slits show in the neck. Notice how similar this embryo is to the slightly larger turtle twins in Fig. 225. (Photograph furnished by Department of Anatomy, Chicago University.)

fishes on the one hand and the terrestrial Anurans on the other. This was especially evident in their method of locomotion and in their gills both of which were lost when the tadpole became a frog. The frog is thus said to pass through stages that resemble permanent conditions in lower forms of life.

These changes in the development of the frog were readily observed and satisfied your most critical tests of their actual existence and subsequent history. The same kind of evidence is present in the embryonic study of the higher animals (Figs. 224 and 225). The more one studies the embryology of animals the more one becomes convinced that animals pass through many stages which are characteristic of the adult life of animals lower in the scale of organization. In doing this they appear to be repeating their own ancestral history, with the result that we find some structures that appear during the embryonic stages only, such as the gill-slits in turtles and man, structures which neither ever uses. As a product of the numerous studies in embryology, the law of recapitulation has been formulated. This law states that in development all animals repeat their ancestral history, even passing through stages which resemble permanent adult conditions in animals in the unrecorded past.

Evolution.—As the word evolution came into early use it had reference to the manner in which organisms during growth gradually acquire adult characters. Thus the notion of an unrolling or unfold-

ing was from the first associated with the term. Such a view assumes that certain conditions have preëxisted and that there is a direct relation between the structures that finally appear and those that give rise to them. The most important part of this early conception is the part which has to do with the idea that present conditions are related to past causes.

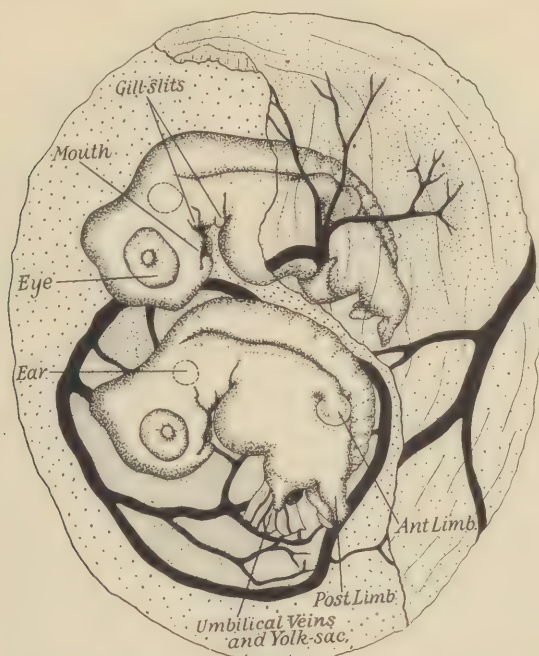


FIG. 225.—Turtle-twins, 9 mm. long. The germinal disk has been partly removed from the upper embryo. The gill-slits have begun to disappear at this stage. The turtle has gill-slits, although it never uses them. This drawing also illustrates that two embryos can be produced in a single egg. Compare with Fig. 224. *The Biology of Twins*, by Newman, gives an interesting account of twinning in man and mammals.

In the broad use of the word evolution it may be applied to the development or unfolding of the cosmic universe, to the geological history of America, to the racial development of the Anglo Saxons, to the growth of the Constitution of the United States or to the origin of the English language. We may properly speak of the evolution of these and kindred problems when analyzed from the viewpoint of cause and effect. Our interest, however, is in organic evolution.

The philosophy of organic evolution tries to explain the facts just summarized. These facts are more completely organized today than

at any previous time, and because of this a clearer understanding of some aspects of evolution has been gained which makes it impossible to accept some of the older views, although they are still very important. To be able to formulate an explanation of the significance of organic life and the manner in which this life has come to be differentiated into an almost endless number of species requires a profound insight into the forces and processes that control and take place in living protoplasm.

From the time of Aristotle down through the dark ages to Erasmus Darwin (1731-1802) various men tried to formulate some of the fundamental principles of evolution. The most successful of all of these was Lamarck.

Lamarck's (1744-1829) life is the old, old story of a man of genius who lived far in advance of his age, and who died comparatively unappreciated and neglected. In this history of the development of the idea of evolution he is the most prominent figure between Aristotle and Charles Darwin. His treatise *Philosophie Zoologique* shows, "First, the certainty that species vary under changing external influences; second, that there is a fundamental unity in the animal kingdom; third, that there is a progressive and perfecting development." To Lamarck is given the credit for having been the first to formulate a definite theory of evolution.

Lamarck is chiefly known for the four laws of evolution which Osborne translates as follows: (1) The Law of Growth. Life by its internal forces tends continuously to increase the volume of everybody that possesses it, as well as to increase the size of all the parts of the body up to a limit which it brings about. (2) The Law of Functional Reaction. The production of a new organ or part results from a new need or want, which continues to be felt, and from the new movement which the need initiates and continues. (3) The well-known Law of Use and Disuse. The development of organs and their force or power of action are always in direct relation to the employment of these organs. (4) Use Inheritance. All that has been acquired or altered in the organization of the individuals during their life is preserved by generations and transmitted to new individuals which proceed from those which have undergone these changes. Lamarck, like Erasmus Darwin, accepted spontaneous generation, for he held that Nature was always creating elemental plants and animals.

The fourth law of Lamarck is the one that has received the most criticism, as it is really fundamental to his whole conception of evolu-

tion, assuming as it does the inheritance of acquired characters (page 284). This law was accepted without question for a hundred years until Weismann challenged the supposed fact of the inheritance of acquired characters. A large literature has accumulated about this problem with many prominent scientists on each side of the

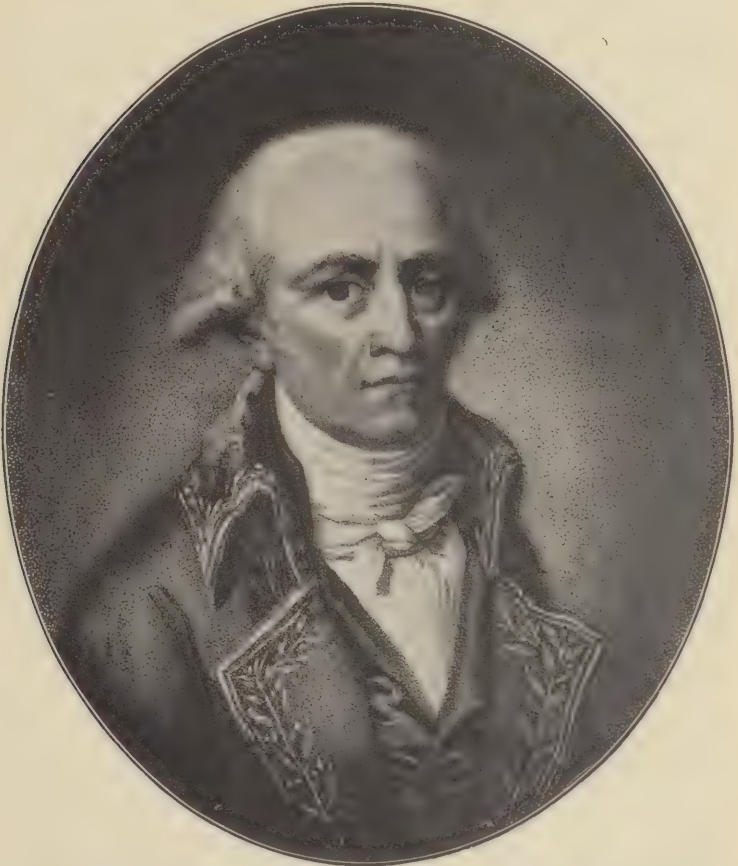


FIG. 226.—Lamarck (1744–1829). (From Loey's *Biology and its Makers*.)

controversy with the result that there has grown up a school of writers on organic evolution known as neo-Lamarckians, who defend in a modified form Lamarck's views; and an opposing school known as neo-Darwinians, who hold that Darwin's conceptions furnished the true explanation.

Much of the bitterness of this controversy has died down because it has come to be recognized that it is not so much a question of theory as of actual experiment. The really crucial tests revolve around experiments that deal directly with the germ cells. This is the reason why the experiments (page 285) of Castle are given so much importance. But there must be many more successful experiments before we can regard the question as proved.

The third law of Lamarck gives one a clear idea of the method of development of general bodily characters, such as bones, muscles, etc., but it does not explain how a protective coloration (Fig. 192), may have started. We thus have to make an exception to this general law and apply it only in a limited manner.

The questions and objections raised to the third and fourth laws of Lamarck give you some idea of the nature of the criticisms that many regard as valid against Lamarck. This in no way, however, detracts from the great credit that will always belong to him for having been the first to formulate a philosophic explanation of organic life.

Charles Robert Darwin (1809-1882), the great naturalist and author, by his interpretation of organic life as a result of his study, made a most notable contribution to our conception of evolution.

From 1831 to 1836 he acted as naturalist on H. M. S. *Beagle*, which made an extensive surveying expedition. During this time he thought and read about the collections of fossil and living forms made by the *Beagle*, and he says that it was "by far the most important event in my life, and has determined my whole career." On his return he published his observations in *A Naturalist's Voyage*, which is one of the most delightful records of a naturalist's travels ever produced.

Darwin owed a great deal to his predecessors, more than is generally believed, because a rather complete conception of evolution had already been reached, and some of the evidence stated. He was strongly influenced by reading Lyell's *Principles of Geology*, and later while studying domestic animals he read Malthus *On Population*, as a result of which "the idea of selection in a state of nature first occurred to him as a result of the struggle for existence, or rather for life, between different individuals and species." Darwin's great contribution to evolution is the *Origin of Species* as a result of a struggle, utilizing variations and letting nature select, which is what is meant by the term "Natural Selection" or the "Survival of the Fittest." "Natural selection, then, is a theory which seeks to explain by natural causes the occurrence of every

kind of adaptation which is to be met with in organic nature, on the assumption that adaptations of every kind have primary reference to the preservation of species, and therefore also, as a general rule, to the preservation of their constituent individuals."



FIG. 227.—Charles Darwin (1809-1882). (From Loey's *Biology and its Makers*.)

Variation is the key-note to Darwinism, and one of the chief lines of research since his time has been to determine the causes of variation. Some idea of Darwin's notion in regard to variation is to

be gained from the following: "It seems clear that organic beings must be exposed during several generations to new conditions to cause any great amount of variation, and that when the organism has once begun to vary, it generally continues varying for many generations. No case is on record of a variable organism ceasing to vary under cultivation. Our oldest cultivated plant, such as wheat, still yields new varieties; our oldest domesticated animals are still capable of rapid improvement or modification."

During the time of Lamarck and Darwin the opinion was very general that species were immutable and remained so unless changed by a distinct creation. Today it is regarded as a difficult problem to formulate a satisfactory definition of species. Darwin maintained that varieties arise through individual differences. "Hence I look at individual differences, though of small interest to the systematist, as of the highest importance to us, as being the first steps toward slight varieties as are hardly worth recording in natural history. And I look at varieties which are in any degree more strongly marked and permanent, as steps toward more strongly marked and permanent varieties; and at the latter as leading to subspecies." . . . "Again it may be asked, How is it that varieties which I have called incipient species, become ultimately converted into good and distinct species, which in most cases obviously differ from each other far more than do the varieties of the same species? How do these groups of species, which constitute what are called distinct genera, and which differ from each other more than do the species of the same genus, arise? All of these results follow from the struggle for life. Owing to this struggle, variations, however slight and from whatever cause proceeding, if they be in any degree profitable to the individuals of a species, in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals, and will generally be transmitted to the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term *Natural Selection*, in order to mark its relation to man's power of selection. But the expression often used by Mr. Herbert Spencer of the *Survival of the Fittest* is more accurate and is sometimes equally convenient. We have seen that man by selection can certainly produce great results, and can adapt organic beings to his own uses, through the accumulations of slight but useful

variations, given to him by the hand of Nature. But natural selection, as we shall hereafter see, is a power incessantly ready for action, and is as immeasurably superior to man's feeble efforts as the works of Nature are to those of art."

There has been considerable hysterical writing in regard to the brutality of the struggle for existence which has been read into and superimposed on Darwin's original conception. "I (Darwin) should premise that I use this term in a larger and metamorphical sense, including dependence of one being on another, and including (which is more important) not only the life of the individual but success in leaving progeny. Two canine animals, in time of dearth, may be truly said to struggle with each other which shall get food and live. But a plant in the edge of a desert is said to struggle for life against the drought, though more properly it should be said to be dependent on moisture. A plant which actually produces a thousand seeds of which only one can manage to come to maturity, may truly be said to struggle with the plants of the same and other kinds which already clothe the ground. The mistletoe is dependent on the apple and a few other trees, but can only in a far-fetched sense be said to struggle with these trees, for if too many of these parasites grow on the same tree, it languishes and dies. But several seedling mistletoes, growing close together in the same branch, may more truly be said to struggle with each other. As the mistletoe is disseminated by birds, its existence depends on them, and it may metaphorically be said to struggle with other fruit-bearing plants in tempting the birds to devour and thus disseminate its seeds. In these several senses, which pass into each other, I use for convenience' sake the general term 'Struggle for Existence.' "

In these extracts in Darwin's own words, we have his methods of interpreting changes in living things. Though he was one of the most abused men of the past century, he lived to see many turn to his views. At the close of the century *The Outlook* held a canvass of opinion as to the greatest book written from 1800 to 1900 and Darwin's *Origin of Species* received the largest number of votes as being the book that has had the greatest influence in molding the thought of the century. This fact alone is sufficient to justify the claim that one cannot properly understand the intellectual development of the civilized world between 1850-1900 without reading the *Origin of Species*.

As to Darwin's theory of Natural Selection there has been from the first serious doubt that new species actually do arise through the

accumulation of minute variations, for if Nature selects those forms of life that have a variation or group of variations then these variations must be of such a character that they are actually helpful.



FIG. 228.—*Archæopteryx lithographica*. This interesting fossil, which has teeth, fingers and a tail similar to members of the Reptile group, has hind limbs and feathers characteristic of birds. Such fossils as *Archæopteryx* help to explain how some of the evolutionary transitions took place. (After Dames.)

But most of Darwin's recorded variations are so minute that it is impossible to conceive how they could come under the influence of the selective process.

It is especially difficult to see how such minute variations would give rise to organs of extreme perfection and complexity such as the vertebrate eye. Even Darwin doubted that natural selection is



FIG. 229.—The long-necked giraffe. Courtesy of New York Zoölogical Society.
(Photographed by E. N. Sanborn.)

responsible for such a structure, for he says: "To suppose that the eye with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest degree."

The following illustration contrasts the difference between the views of Lamarck and Darwin: The giraffe is known to have a very long neck, although there are no more cervical vertebræ in the neck of the giraffe than in the neck of man, dog or horse. Lamarck argued that the giraffe's neck was lengthened by adding together from generation to generation the slight increments due to exercise (use) of each

individual in reaching upward for food in the trees. Darwin's conception on the other hand assumes that this lengthening is due to the elimination in periods of stress of the shorter-necked individuals and the preservation of the longer-necked individuals that were able to live because they could secure the necessary food.

Darwin found it necessary to supplement his general theory of natural selection which did not explain the many differences between the sexes of animals that pair. To account for these, he formulated what is known as the theory of *Sexual Selection*. "This form of selection depends, not on a struggle for existence in relation to other organic beings or to external conditions, but on a struggle between individuals of one sex, generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection. Generally the most vigorous males, those which are best fitted for their place in nature, will leave most progeny. But in many cases victory depends, not so much on general vigor, as on having special weapons confined to the male sex (Fig. 173). A hornless stag or spurless cock would have a poor chance of leaving numerous offspring. Sexual selection, by always allowing the victor to breed, might surely give indomitable courage, length to the spur, and strength to the wing to strike in the spurred leg in nearly the same manner as the brutal cock-fighter by the careful selection of his best cocks." This theory is fully discussed by Darwin in Part II of *Descent of Man*.

So many exceptions have been found to Darwin's contention, together with the necessary assumptions that a high degree of esthetic taste exists in many of the females, that most biologists have rejected his theory of sexual selection. Reference is made to this theory of Darwin's because it serves admirably as an illustration of the important fact that there is not at present any completely satisfactory explanation of the origin of secondary sexual characters and sexual dimorphism.

The illustrative forms of criticism against Lamarck's and Darwin's conception of organic evolution should not raise any doubt in your mind about the fact of organic evolution itself. The theory that modern animals and plants have been derived by modifications from preëxisting animals and plants is regarded as an established fact by all biologists today. The mere fact that one or several men have not been able to state completely just how this descent took place should not lead you into that confused state of thinking that there has

been no descent. Light travelling from stellar space may not reach our earth until more than a thousand years after it started earthward. The star which gave off these light rays may have gone out of existence many years ago, even before America was discovered; so far as we can prove we shall not know until certain light rays cease to reach us. What keeps them going? Shall we deny their existence because we cannot explain all of the conditions governing them? This familiar illustration helps us to realize that our understanding of many great problems is still far from complete.

Instead of rejecting a given explanation or theory because it does not satisfy all of the conditions, the better part of wisdom is to try to understand the known factors such as are summarized for organic evolution on page 287, and see to what extent they can be explained. When the great mass of experimental data that has been collected during the past fifteen years in biology is properly organized and interpreted, we shall gain a clearer insight into the method of organic evolution. In the meantime we should not fail to remember that Lamarckism was of great value in giving us a conception of organic evolution, and that many scientific thinkers believe that Darwin's theory of natural selection is a real factor in the explanation of organic evolution.

REFERENCES.

- CONN: Method of Evolution.
 COULTER: Evolution.
 DARWIN: Origin of Species, Descent of Man, Animal and Plants under Domestication.
 KELLOGG: Darwinism Today.
 PACKARD: Lamarck, His Life and Works.
 OSBORN: From the Greeks to Darwin, Origin and Evolution of Life.
 THOMPSON: Evolution, Darwinism and Human Life.
 JORDAN and KELLOGG: Evolution and Animal Life.
 LOCY: Biology and its Makers.
 WAL LACE: Darwinism.

In a number of elementary Biologies, one section, at the close of the book, is devoted to the relations of man to the several problems treated. The writer recognizes the great importance of man in his biological relations, but throughout this book the aim has been to present the fundamental principles of protoplasm as they apply to all living things of which man is but one. The writer recognizes that many of the topics have received but brief mention and others are omitted simply because his book aims to be only an introduction to this important field of learning. For those who wish assistance in beginning the fascinating study of the relation of the general

principles of biology to man, the following special references furnish a good introduction:

REFERENCES.

- CRAMPTON: The Doctrine of Evolution, Chapters V to VIII.
DARWIN: Descent of Man.
HUXLEY: Man's Place in Nature.
JORDAN and KELLOGG: Evolution and Animal Life, Chapter XXI.
KEANE: Man Past and Present.
LA CONTE: Evolution and its Relation to Religious Thought.
LULL: Organic Evolution, Chapters XXXVII to XXXVIII.
METSCHNIKOFF: The Nature of Man.
OSBORNE: Men of the Old Stone Age.
PEARSE: General Zoölogy, Chapter XXVII.
TYLER: The Whence and Whither of Man.
WALLACE: Man's Place in the Universe.

APPENDIX.

CLASSIFICATION OF ANIMALS AND PLANTS.

Animal Kingdom.—The following general plan of classifying the animal kingdom is taken from Parker and Haswell, and serves to show how animals are grouped, but does not determine the exact relation of even the great phyla.

I. Phylum Protozoa, 8000¹ species living.

Classes 1. Rhizopoda: ameba.

2. Mycetozoa.

3. Mastigophora: spirochetes, trypanosomes.

4. Sporozoa: gregarines, all parasitic.

5. Infusoria:

Class Ciliata.

Order, Holotrichida.

Family, Paramedicæ.

Genera, Paramecium.

Species: Paramecium caudatum, Paramecium aurelia.

II. Phylum Porifera, 2500 species.

Class Porifera; sponges.

III. Phylum Celenterata: 4500 species.

Classes 1. Hydrozoa: hydra, sea-anemone, jelly-fish.

Hydrariæ.

Hydra viridis.

Hydra fusca.

2. Scyphozoa: jelly-fish.

3. Actinozoa: corals.

4. Ctenophora.

IV. Phylum Platyhelminthes: 5000 species.

Classes 1. Turbellaria: flatworms.

2. Trematoda: liver fluke.

3. Cestoda: tape-worms.

¹ The estimate of the number of species in each phylum is by H. S. Pratt.

V. Phylum Nemathelminthes, 1500 species.

- Classes 1. Nematoda: ascaria, trichina, uncinaria.
- 2. Acanthocephala: hook-headed worms, echino-rhynchus.
- 3. Chetognatha.

VI. Phylum Trochelminthes, 500 species.

- Classes 1. Rotifera.
- 2. Dinophilea.
- 3. Gastrotricha.

VII. Phylum Molluscoidea, 1700 species.

- Classes 1. Polyzoa.
- 2. Phoronida.
- 3. Brachiopoda.

VIII. Phylum Echinodermata, 4000 species.

- Classes 1. Asteroidea: star-fish.
- 2. Ophiuroidea: brittle stars.
- 3. Echinoidea: sea-urchins.
- 4. Holothuroidea: sea-cucumbers.
- 5. Crinoidea: crinoids.

IX. Phylum Annulata, 4000 species.

- Classes 1. Chetopoda: earthworms.
- Oligocherta.
- Lumbricidæ.
- Lumbricus terrestris: Common earthworm.
- 2. Gephyrea.
- 3. Hirudinea: leeches.

X. Phylum Arthropoda, 394,000¹ species.

- Classes 1. Crustacea: Crabs, lobsters, etc.
- Macrura.
- Astacidæ.
- Astacus Cambarus: Common crayfish.
- 2. Onychophora.
- 3. Myriapoda: centipedes.
- 4. Insects.
- 1. Order Aptera: spring-tails, snow-fleas.
- 2. Order Ephemeridæ: May-flies.
- 3. Order Odonata: dragon-flies, damsel-flies.
- 4. Order Plecoptera: stone-flies.
- 5. Order Isoptera: white ants.
- 6. Order Corrodentia: book-lice, bark-lice.

¹ Some authorities estimate that the insects alone number 600,000.

7. Order Mallophaga: biting bird-lice.
8. Order Thysanoptera: thrips.
9. Order Euplexoptera: earwigs.
10. Order Orthoptera: cockroaches, grass-hoppers.
11. Order Hemiptera: bugs, head-louse.
12. Order Neuroptera: ant-lion, dobson-fly.
13. Order Mecoptera: scorpion-flies.
14. Order Trichoptera: caddis-flies.
15. Order Lepidoptera: butterflies, moths.
16. Order Diptera: flies.
17. Order Siphonaptera: fleas.
18. Order Coleoptera: beetles, potato-bug.
19. Order Hymenoptera: bees, ants, wasps.

Apidæ.

Apis mellifica. Honey bee.

XI. Phylum Mollusca, 61,000 species.

Classes 1. Pelecypoda: clams, oysters.

Unionidæ.

Anontoides.

Anodonta fluviatiles.

2. Amphineura.

3. Gastropoda: snails.

4. Cephalopoda: squid, devil-fish.

XII. Phylum Chordata.

Subphylum 1. Adelochorda.

2. Urochorda: tunicate, 1300 species.

3. Vertebrata.

Acrania: amphioxus.

Craniate.

Classes 1. Cyclostomata: lamprey.

2. Pisces: fishes, 13,000 species.

3. Amphibia: 1400 species.

Urodela: salamanders.

Anura: frogs and toads.

Salienta.

Ranidæ.

Rana pipiens.

Rana catesbiana.

Rana clamitans.

4. Reptilia: horned toad, lizard, snake, turtle, alligator, 3500 species.

5. Aves: birds, 13,000 species.

6. Mammalia: dog, cat, sheep, seal, rabbit, monkey, man, etc., 3500 species.

The Plant Kingdom.—Largely from Bergen and Caldwell.

Phylum I. Thallophyta.

Subphylum I. Myxomycetes: slime moulds, sometimes classed as animals.

Subphylum II. Schizophyta. 2020 species.

Class I. Schizomycetes: bacteria.

Class II. Schizophyceæ: blue-green algæ.

Subphylum III. Algæ.

Class I. Chlorophyceæ: the green algæ, 8950 species.

Class II. Pheophyceæ: the brown algæ, 1030 species.

Class III. Rhodophyceæ: the red algæ, 3050 species.

Subphylum IV. Fungi. 64,400 species.

Class I. Phycomycetes: moulds and mildews.

Class II. Ascomycetes: mildews, cup-fungi, etc.

Class III. Lichens.

Class IV. Basidiomycetes: mushrooms, rusts, etc.

Phylum II. Bryophyta.

Class I. Hepaticæ: liverworts, 4000 species.

Class II. Musci: mosses, 12,600 species.

Phylum III. Pteridophyta.

Class I. Filicineæ: true ferns, 3800 species.

Class II. Equisetinæ: scouring rushes or horse-tails, 24 species.

Class III. Lycopodineæ: club mosses or ground pines, 700 species.

Phylum IV. Spermatophyta.

Subphylum I. Gymnosperms, 540 species.

Order. Coniferales: pine, spruce, firs, etc.

Subphylum II. Angiosperms.

Order I. Monocotyledons: corn, grasses, lilies, etc., 23,700 species.

Order II. Dicotyledons: hardwood trees, roses, etc., 108,800 species. †

INDEX.

A

ABIOGENESIS, 112
 Adductor muscle, 167
 Adrenal body, 30
 Afferent nerve, 164
 Allolobophora fetida, 165
 Amanita muscaria, 212
 phalloides, 212
 Amino-acid, 39
 Amitosis, 105. *See* Fission.
 Amphibia, 19
 Amylopsin, 40
 Anaphase, 56
 Anasa tristis, 273
 Animal pole, 71
 Anodontia fluviatiles, 169
 Anopheles maculipennis, 217
 Antenna, 176
 Antitoxin, 228
 Apis mellifica, 182
 Archæopteryx lithographica, 296
 Aristotle, 112, 290
 Asexual, 149, 186
 Aspergillus niger, 128
 Associational neuron, 64, 164
 Astacus, 171
 Astral fibers, 74
 Auricle, 42
 Autotrophic, 100
 Axis-cylinder, 62
 Axon, 62

B

BABCOCK, 50
 Bacterium tumefaciens, 216
 Bees, 181-191
 Bell, 265
 Bile, 28
 Biogenetic law, 142
 Bladder, 30
 Blood, 43, 159
 corpuscles, 43, 159
 Bowfin, 246
 Branchiobdella pulcherrima, 206
 Brooks, 239
 Bufo cognatus cognatus, 253
 valliceps, 253

20

C

CALCIUM, 102, 114
 Callinectes sapidus, 234
 Caltha palustris, 268
 Carbohydrate, 37, 100, 176
 Carbon, 100, 114
 Cardia, 27, 175
 Castle, 267, 284
 Cell, 55
 Centrosome, 74
 Charcharodon megalodon, 245
 Chitin, 172
 Chittenden, 47
 Chlorella vulgaris, 156
 Chlorophyll, 100
 Chloroplast, 99, 124, 156
 Chromatin, 74, 271
 Chromosome, 76, 276
 Cimex lectularius, 194
 Classification, 19, 20, 23
 Cleavage, 79
 Clitellum, 160
 Cloaca, 28, 30
 Cnidocil, 147
 Cocoon, 161
 Coelom, 32
 Colony, 182
 Columella, 27
 Conductivity, 94
 Contractility, 94
 Cootie, 223
 Corpora adiposa, 32
 Crotalus adamantus, 210
 Cryptobranchus, 74
 Cuticle, 163
 Cuvier, 19, 33

D

DARWIN, 290, 292
 Dendrite, 62
 Deutoplasm, 71
 Digestion, 38, 92, 155
 Digestive glands, 28
 liver, 28
 pancreas, 28
 Disaccharid, 37
 Dissepiment, 159

Doncaster, 279
Dox, 128

E

EAR, 26
Ecdysis, 172
Ectoderm, 80, 146, 161
Ectoplasm, 86
Effector nerve, 63
Efferent, 164
Embryology, 33
Endoderm, 80, 147, 161
Endoplasm, 86
Endopodite, 173
Enzyme, 38; Chapter X, 110
Epithelium ciliated, 163
 columnar, 163
 pavement, 163
Esophagus, 27
Eustachian, 26
Excretion, 46
Exopodite, 173
Exoskeleton, 172

F

FATS, 37, 100
Fermentation, 39
 unorganized, 39
Fertilization, 78, 93, 127, 272
Fission, 93, 108, 126
Food, 35, 176
Fossil, 243

G

GALL-BLADDER, 28
Galton, 279
Ganglion, 160, 164, 177
Genes, 273
Germ layer, 80
Gill, 169
Glochidium, 198
Glottis, 27
Gonium, 142

H

HARGITT, 155
Harper, 277
Helix pomatia, 227
Heredit, 269
Hemoglobin, 45
Hermaphrodite, 32, 160
Heterotrophic, 100
Hibernation, 25, 29, 48, 156
Hinge ligament, 167

Homology, 174
Hooke, 56
Hormone, 38
Horned toad, 245
Huxley, 113
Hydra fusca, 145
 viridis, 145
Hydrogen, 100, 114

I

IMMUNITY, 228
Irritability, 94, 159

J

JENNER, 228
Jennings, 96, 262, 296
Jordan, 257

K

KELLOGG, 265
Kidney, 30
Klippspringer, 229

L

LAMARCK, 290
Lavoisier, 46
Le Conte, 120
Leucocytes, 160
Life cycle, 83, 97, 141
Linnaeus, 19, 23
Lull, 234
Lungs, 28
Lumbricus terrestris, 158
Lyell, 292
Lysiplebus tritici, 204

M

MACROGAMETOCYTE, 218
Magnesium, 102, 114
Maize, 278
Malpighian body, 30
Mantle, 168
Maturation, 74, 272
Melanoplus femur-rubrum, 265
Mendel, 274
Mesoderm, 80, 161
Mesoglea, 146
Metabolism, 47, 93, 102, 106
Metamerism, 158, 172, 181
Metamorphosis, 83
Metaphase, 56

Metatrophic, 110
 Metcalf, 235
 Micrococcus melitensis, 224
 Microgametocyte, 218
 Micon, 86, 107
 Migula, 107
 Mitotic, 74, 108
 Monosaccharid, 37, 101
 Morphology, 33
 Movement, 17-18, 68, 94
 Müller, 48
 Musca carnaria, 234
 Muscle scars, 167
 Mussel community, 256
 Myelin sheath, 63

N

NARES, 26, 28
 Nematocysts, 147
 Nephridia, 160, 176
 Neurilemma, 63
 Neurite, 62
 Neuron, 62, 164
 Nitrogen, 100, 110
 Nucleus, 57
 endosperm, 141
 macro-, 89
 micro-, 89
 segmentation, 79

O

OMATIDIUM, 179
 Oöcyte, 71, 271
 Oögonia, 271
 Oöspore, 127
 Organ, 19
 Organism, 18-19
 Ostia, 177
 Ovary, 30, 69, 160
 Ovid, 112
 Oviduct, 30, 160
 Oxygen, 29, 46, 93, 76, 106, 114, 184, 232
 Ozone, 46

P

PALPS, 170
 Paratrophic, 110
 Parasite, 123, 195-204
 Parker, 274
 Parthenogenesis, 186
 Pasteur, 118
 Pearl, 263
 Pencillium camemberti, 128
 Pepsin, 39
 Phagocyte, 45, 160

Phillips, 267
 Photosynthesis, 102
 Physiological division labor, 33
 Physiology, 33
 Piltown skull, 248
 Plasma, 45
 Plasmodium malaria, 218
 præcox, 218
 Pollenization, 140
 Polysaccharid, 37
 Potassium, 102
 Pronucleus, female, 77, 272
 male, 78, 272
 Prophase, 56
 Protein, 36, 100, 176
 conjugate, 36
 derived, 36
 simple, 36
 Protoplast, 98
 Prototrophic, 10
 Prenoid, 124
 Ptarmigan, 258
 Pyloric, 27, 175

R

RANA catesbiana, 18, 23, 73, 83, 120, 252
 clamitans, 22
 draytonii, 22
 pipiens, 22, 120, 252, 288
 sylvatica, 21, 67, 252
 temporaria, 20
 Ranunculus bulbosus, 267
 Receptor neuron, 64
 Redi, 113
 Regeneration, 162

S

SALMINCOLA edwardsii, 200
 Saprophyte, 123
 Sassafras, 243
 Schæffer, 68
 Schizophysea, 100, 107
 Schleiden, 56
 Schwann, 56
 Scientific method, 239
 Secretion, 38
 internal, 38
 Segmentation nucleus, 79
 Seminal receptacle, 160
 vesicle, 160
 Sexual, 149
 Siphon, 169
 Skin, 28
 Somite, 158
 Spallanzani, 113
 Spencer, 294
 Sperm, 31, 70

Spermary (testis), 61, 160, 177
 Spermatocyte, 271
 Spermatogonia, 271
 Spindle, 76
 Spiracle, 184
 Spleen, 28
 Spore, 105
 Sporotrichium, 214
 Sporozoite, 218
 Starvation, 48
 Steapsin, 40
 Steno, 243
 Stiles, 221
 Stomach, 27
 Strychnos, 230
 Stylophthalemus paradoxus, 256
 Sulphur, 102, 114
 Swimmerets, 174, 177
 Symbiont, 123

T

TÆNIA saginata, 197
 Taxonomist, 23
 Teeth, 26
 vomerine, 26
 Tissue, 52
 connective, 53
 epithelial, 52
 muscular, 54
 nervous, 55, 62
 Tongue, 26
 Toxin, 110
 Toxoptera groninum, 204
 Trachea, 18
 Trillium grandiflorum, 132
 Trypanosome gambiense, 224
 Trypsin, 40
 Tympanic membrane, 27
 Tyndall, 112

U

UMBONE, 167
 Ureter, 30

Urogenital duct, 31
 Uterus, 30

V

VACUOLE, contractile, 87, 93
 gastric, 92
 Variation, 262
 Vegetal pole, 71
 Ventricle, 42
 Venus mercenaria, 246
 Vertebrata, 19
 de Vince, 243
 Virgil, 112
 Virginia deer, 259
 Volvox, 143
 Vorticellidæ, 142

W

WAGNER, 148
 Wallace, 260
 Ward, 210
 Webster, 204
 Weismann, 273
 Wheeler, 206
 Wiedersheim, 269
 Wilson, 57, 153
 Woodcock, 260
 Woodworth, 234

Y

YERKES, 165

Z

Zoöspore, 126
 Zoötoxia, 111
 Zygospor, 125, 129





WERT
BOOKBINDING
MIDDLETOWN, PA.
JANUARY 75
We're Quality Bound

QH 308 S635t 1920

05031040R



NLM 05033619 9

NATIONAL LIBRARY OF MEDICINE